NASA-CR-193791

60 p

Annual Report

for the period July 1, 1988 to June 30, 1989

North Carolina State University
and
North Carolina A&T State University

MARS MISSION RESEARCH CENTER

a University Space Engineering Research Center
supported by NASA Grant NAGW-1331

National Aeronautics and Space Administration
Office of Aeronautics and Space Technology
Code RS
Washington, DC 20546

Submitted by

Fred R. DeJarnette, Director
Mars Mission Research Center
North Carolina State University
Raleigh, NC 27695-7910

July 1989

Annual Report

for the period July 1, 1988 to June 30, 1989

North Carolina State University
and
North Carolina A&T State University

MARS MISSION RESEARCH CENTER

a University Space Engineering Research Center
supported by NASA Grant NAGW-1331

National Aeronautics and Space Administration
Office of Aeronautics and Space Technology
Code RS
Washington, DC 20546

Submitted by

Fred R. DeJarnette, Director
Mars Mission Research Center
North Carolina State University
Raleigh, NC 27695-7910

July 1989

EXECUTIVE SUMMARY

The Mars Mission Research Center (M^{2}RC) is one of nine University Space Engineering Research Centers established by NASA's Office of Aeronautics and Space Technology in June, 1988. The goal of the M^{2}RC is to focus on research and training technologies for planetary exploration with particular emphasis on Mars. The research combines (1) hypersonic aerodynamics, (2) light-weight structures and controls, and (3) composite materials and fabrication and propulsion in a cross-disciplined program directed towards the development of space transportation systems for planetary travel. The Center is responsible to the NASA Team of Monitors and an Academic Board which is composed of the deans and department heads of the participating faculty.

Hypersonic aerodynamics will determine the exterior flowfield and surface conditions for aerodynamic braking during entry into the atmospheres of Mars and Earth. This information is used by the structures and materials investigators in the design and fabrication of an aeroshell. Light-weight structures and controls are involved in the interface between the aeroshell and payload. Composite materials and fabrication have three major thrusts: (1) analysis and modeling of braided and woven composites, (2) micro-and macro-mechanics and testing of the composites, and (3) processing and fabrication from pre-forms developed by the faculty in Textiles. During this initial year, efforts have been directed towards developing the computational facilities, laboratories, and equipment necessary to conduct this research. In addition to the research, students are being trained in space related topics which will give them the background to pursue careers in the space program at universities, industries, or NASA Centers and other governmental laboratories.

The M^{2}RC was formed in June, 1988 with 14 faculty, 8 graduate, and 9 under-graduate students in the Colleges of Engineering and Textiles at NCSU and School of Engineering at A&T. It has now increased to 21 faculty, 12 graduate, and 12 under-

graduate students. Minority participation started with no faculty, 2 graduate and 3 undergraduate students. We now have one faculty, 3 graduate, and 3 undergraduate minorities. The participation of women include one faculty, 3 graduate, and 3 undergraduate students. We have found that undergraduate minorities and women are more likely to become interested in graduate programs if they are involved in research with the faculty and graduate students in their undergraduate program. In addition, the summer research at one of the NASA Centers or participating industries attract many students to our graduate program.

Interactions with NASA Ames and Langley Research Centers have led to summer programs and additional support from them. Discussions with the McDonnell Douglas Corporation at Huntington Beach, California and St. Louis, Missouri have resulted in contracts. with the M^2RC and a student summer intern. Interactions with other government laboratories, industries and universities are being pursued.

Funding from NASA was $500,000 for the first year (June, 1988 to February 28, 1989) and for the second year (March 1, 1989 to February 28, 1990) it is $1,962,518. Cost sharing from the universities was $218,673 in the first year (44% of the NASA funding) and $944,572 for the second year (48% of NASA funding). The cost sharing included faculty and support personnel, equipment, and space. A new research building is planned for the Centennial Campus at NCSU in the winter of 1991 which will provide offices and laboratories (7,000 sq. ft.) for the M^2RC faculty and students. In addition, construction is underway to house the entire College of Textiles there by fall of 1990. Renovation of facilities at A&T are in progress for laboratories there. The State of North Carolina has provided funding for supercomputers to support research projects. For the Research Triangle Area (Raleigh, Durham, and Chapel Hill) a Cray YMP has been ordered and is expected to be operational in August, 1989. A Convex C120 supercomputer has been installed at A&T to support research projects which includes M^2RC.

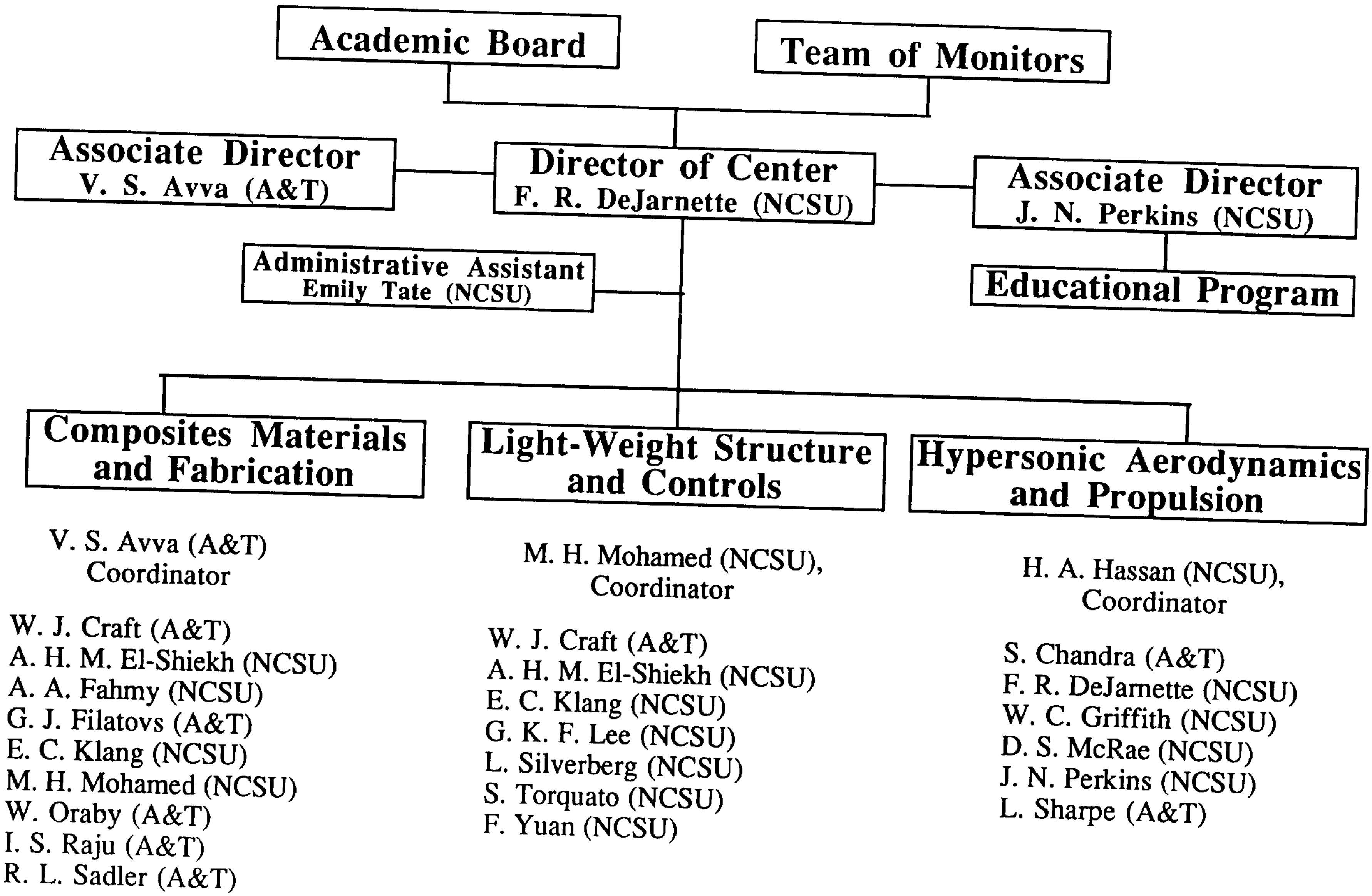
The faculty have been active in obtaining additional funding from other sources. They currently have 22 grants and contracts for research related to $M^2RC$and 8 additional contracts and grants for research not related to M^2RC. All faculty participants are working on obtaining additional funding for research related to M^2RC in order to continue in the Center beyond the second year. This step, along with the current additional funding, should insure that the Center will become self-sustaining in five years.

Faculty and students have been active in presenting papers at national and international meetings as well as publishing results in reports and archival journals. Additional publicity on the M^2RC and the research being performed has been provided by numerous newspaper and magazine articles, press releases, and radio and television programs. The M^2RC plans to increase the dissemination of research by hosting a Work Shop next fall. The activities of the M^2RC are expected to have a significant influence on the space program, and to help gain the support of the nation for a dedicated space program.

CONTENTS

LIST OF FIGURES

Organizational Structure



ORGANIZATIONAL STRUCTURE

North Carolina State University (NCSU)
and
North Carolina A&T State University (A&T)

MARS MISSION RESEARCH CENTER (M^2RC)

Director - F. R. DeJarnette (NCSU)
Administrative Assistant - Emily Tate (NCSU)
Associate Directors - V. S. Avva (A&T)
J. N. Perkins (NCSU)

RESEARCH AREAS:

<u>Composite Materials and Fabrication</u>
Coordinator - V. S. Avva
Researchers - W.J. Craft (A&T), A. El-Shiekh (NCSU), G. J. Filatovs (A&T), E. C. Klang, (NCSU), A. Fahmy (NCSU), M. H. Mohamed (NCSU), W. Oraby (A&T), I. S. Raju (A&T),F. L.Sadler (A&T), L. Silverberg (NCSU), S. Torquato (NCSU), F. Yuan (NCSU)

<u>Light-Weight Structures and Controls</u>
Coordinator - M. H. Mohamed (NCSU)
Researchers - W. J. Craft (A&T), A. El-Shiekh (NCSU), E. C. Klang (NCSU), G. K. F. Lee (NCSU), L. Silverberg (NCSU), S. Torquato (NCSU), F. Yuan (NCSU)

<u>Hypersonic Aerodynamics and Propulsion</u>
Coordinator - H. A. Hassan (NCSU)
Researchers - S. Chandra (A&T), F. R. DeJarnette (NCSU), W. C. Griffith (NCSU), D. S. McRae (NCSU), J. N. Perkins (NCSU), L. Sharpe (A&T)

STUDENT PARTICIPANTS

<u>Undergraduates</u>
Andy Barefoot (NCSU), Jinan Bennett (NCSU), Frank Brauns (NCSU), Nancy Evans (NCSU), Ian Gallimore (NCSU), Eric Goforth (A&T), Mr. Shuman (A&T), Arthur Hall (NCSU), David Hash (NCSU), Malcolm Lyon (A&T), Jennifer Riddick (A&T), Hughart Roberts (NCSU), Erik Scott (NCSU), Cirrelia Thaxton (NCSU), Terry Young (NCSU)

<u>Graduate Students</u>
Aaron Cozart (NCSU), Genevieve Dellinger (NCSU), Larry Dickinson (NCSU), Peter Fay (A&T), Jon Hamilton (NCSU), Dean Kontinos (NCSU), Brian Landrum (NCSU), James Packard (NCSU), James Redmond (NCSU), Rona Reid (NCSU), Susan Spry (NCSU), Gregory Washington (NCSU)

NASA MONITORING TEAM

Steve Wander, Chairperson
NASA Headquarters
Code RF
600 Independence Avenue
Washington, DC 20456
(202) 453-2820

Dr. Kenneth Sutton
NASA Langley Research Center
MS 366
Hampton, Virginia 23665-5225
(804) 856-3031

Dr. Steve Deiwert
NASA Ames Research Center
Code RTA
Moffett Field, CA 94035
(415) 694-6198

Dr. Herbert J. Gladden
NASA Lewis Research Center
MS 5-11
Cleveland, OH 44135
(216) 433-5871

Dr. Howard Goldstein
NASA Ames Research Center
Code RTM
Moffett Field, CA 94035
(415)694-6103

Dr. Winston Goodrich
NASA Headquarters
Code RF
600 Independence Avenue
Washington, DC 20546
(202) 453-8781
Johnson Space Center Representative

Dr. James H. Starnes, Jr.
NASA Langley Research Center
MS 190
Hampton, VA 23665-5225
(804) 865-2552

ACADEMIC BOARD

PURPOSE:

1. Work with Center Director to insure that the research and academic programs are consistent
2. Coordinate personnel, space and equipment requirements of the Center.

MEMBERSHIP:

Deans and Department Heads of Participating Faculty

CHAIRPERSON:

Rotating Chairperson, Elected by Membership (except for initial period), for Three-Year Period

MEETINGS: Twice a Year

CURRENT MEMBERSHIP:

Dean L. K. Monteith, Dean of Engineering, NCSU Chairperson

Dean R. A. Barnhardt, Dean of Textiles, NCSU

Dean H. L. Martin, Dean of Engineering, A&T

Dr. J. A. Bailey, Head of Mechanical and Aerospace Engineering, NCSU

Dr. W. J. Craft, Head of Mechanical Engineering, A&T

Dr. J. J. Hren, Head of Materials Science and Engineering, NCSU

Dr. C. D. Livengood, Head of Textile Engineering, Chemistry, and Science, NCSU

INTRODUCTION

In June, 1988 NASA's Office of Aeronautics and Space Technology (OAST) established nine University Space Engineering Research Centers to broaden the nation's engineering capability to meet the critical needs of the civilian space program. One of these centers is the Mars Mission Research Center which is a cooperative program between North Carolina State University at Raleigh (NCSU) and North Carolina A&T State University at Greensboro (A&T). The goal of this center is to develop educational and research programs that focus on the technologies for space exploration with particular emphasis on Mars. The research combines (1) hypersonic aerodynamics and propulsion, (2) composite materials and fabrication, (3) light-weight structures, and (4) spacecraft controls in a cross-disciplined program directed towards the development of space transportation systems.

In 1969 the United States accomplished what many people consider the most significant engineering feat of all time, landing men on the Moon and returning them safely to earth. We consider the next great challenge in space to be the robotic and human exploration of Mars. It will provide the focus which arouses curiosity, stimulates imagination, and offers excitement and adventure.

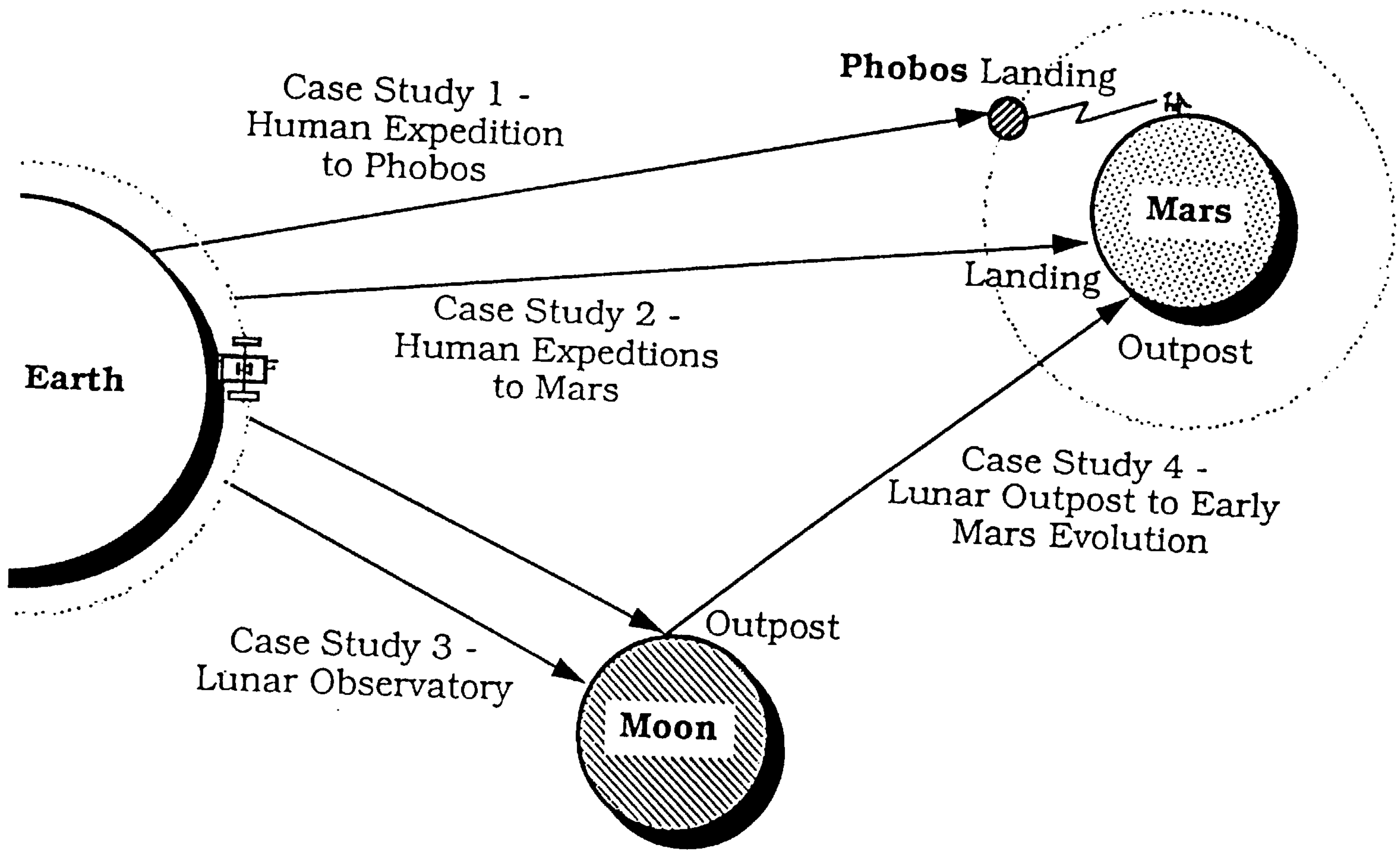
This country landed two unpiloted vehicles on Mars in 1976 as part of the Viking Program. Since that time space exploration by this country has been practically non-existent. A renewed interest started recently, and in 1988 NASA's Office of Exploration identified 3 strategies for the exploration of the Moon and Mars[1]. The first strategy addressed human expeditions for missions to Mars and its two moons. The second was the establishment of a science outpost for a mission to our Moon. The third strategy was an evolutionary expansion which would begin with an outpost on our Moon and progress to a similar base of operations on Mars.

In the same report, four exploration cases were studied. They are depicted on Figure 1 and listed below.

NASA

FIGURE 1 (from Ref. 1)

FY 1988 EXPLORATION CASE STUDIES



1. Human Expedition to Photos
2. Human Expedition to Mars
3. Lunar Observatory
4. Lunar Outpost to Early Mars Evolution

The basic component for each case is the trajectory performed. For trips to our Moon, the path requires only three days to get there and launch opportunities are very frequent. However, an opportunity to launch to Mars occurs only once every 26 months and round trip time could vary from about 400 to 1,000 days, depending on launch date and trajectory type. Three types of trajectories of round-trip trajectories were employed in the Mars exploration case studies: opposition, sprint, and conjunction. Opposition is when Mars, Earth, and the Sun lie in a straight line with the Earth between Mars and the Sun. Conjunction also has Mars, Earth, and the Sun in a straight line except the Sun lies between Earth and Mars. The opposition class allows a Mars - flyby abort and has round-trip times of about 600 days. Sprint is a subset of opposition and requires abort 400 days round trip with high energy requirements. Conjunction class trajectories consume about 1,000 days but has minimum energy requirements. Missions of this duration are considered undesirable because of the uncertainty about human's ability to live in a reduced gravity environment for extended periods of time. An artificial gravity can be designed into the spacecraft, but it increases the complexity, size, safety, and cost of the vehicle significantly.

For human missions, a split/sprint trajectory is employed to minimize trip time. In this technique a cargo spacecraft carrying exploration equipment, return propellant, etc. is launched on a minimum-energy trajectory (conjunction class). The spacecraft carrying the crew is launched one to two years later on a sprint (high energy) trajectory. The two spacecraft would rendezvous near Mars. For some launch years, a Venus swingby may be performed to use its gravity to assist the piloted spacecraft which will reduce launch requirements.

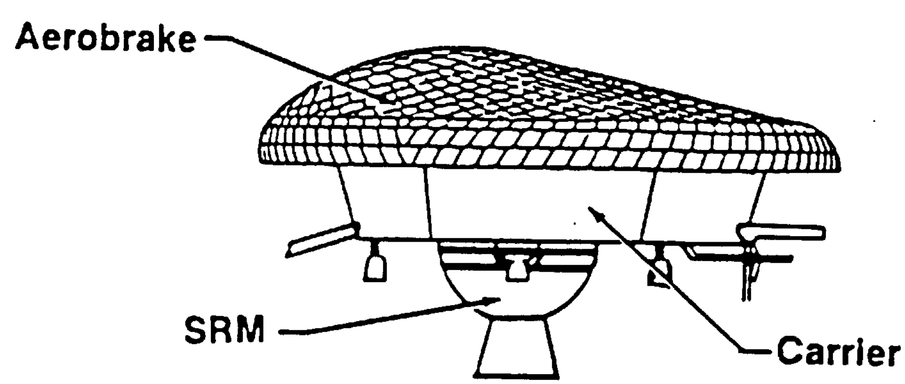
Most studies of trajectories to Mars rely on space stations for the assembly and servicing of vehicles, transfer of crew, and replenishment of propellant. A heavy-lift launch vehicle is used to transport components to a low earth orbit (LEO) space station where the spacecraft would be assembled The spacecraft would be launched from the space station and for the return trip it would dock with the space station. The crew would then be transferred to a Space Shuttle for the flight back to Earth.

A key element in the design of a spacecraft for a Mars Mission is the mechanism needed to reduce the speed of the vehicle at Mars and at Earth for the return trip. The speed reduction required for the sprint class trajectory is much greater than conjunction and opposition trajectories due to the higher approach speeds at Mars and Earth. Two techniques have been considered for slowing the vehicles: propulsive braking and aerobraking. Propulsive braking increases the size and mass of the vehicle significantly due to the extra propellant required. Aerobraking uses aerodynamic drag in the atmospheres of Mars and Earth to slow the vehicle, and it is considered to be one of the most effective ways to reduce the size and mass of the vehicle[2].

Numerous shapes have been proposed for a Mars aerobrake[2,3]. They vary from Apollo-type shapes to winged vehicles, with lift-to-drag (L/D) ratios ranging from about 0.3 to over 1.0. If an artificial gravity is needed, the shape would be even more complicated. At present, it is difficult to define a specific shape because the entry velocity and altitude, control mode, and cross range requirements have not been determined. It is known, however, that the size of the vehicle needs to be about 100 ft. in diameter or larger. For lack of better information, researchers with the Mars Mission Research Center are considering a large (120 ft diameter) Aero-Assisted Flight Experiment (AFE) vehicle as a candidate shape for a Mars Mission. The AFE shape has an ellipsoidal nose tangent to an elliptical cone and a base skirt with the base plane raked relative to the body axis. (See Figure 2). Most of the research, on the other hand, does not presently depend on a specific

FIGURE 2

AEROASSIST FLIGHT EXPERIMENT



AFE SPACECRAFT

shape and can be applied to any shape that is determined from future mission and systems analyses.

This report describes the activities of the students and faculty in the Mars Mission Research Center for the first year (July 1, 1988 to June 30, 1989). A significant part of this time was devoted to recruiting students and faculty, and developing computational facilities, laboratories, and equipment necessary to conduct the research.

METHODOLOGY

The methodology for the research leading to the spacecraft design is illustrated on Figure 3. Mission analysis and trajectory studies are being used to determine configurations and flight conditions for both Mars and Earth entry. The Hypersonic Aerodynamics and Propulsion group are using computational fluid dynamics (CFD), approximate methods, and experimental data to determine surface pressures, temperature, and heat transfer. This information is supplied to the other three groups, Composite Materials and Fabrication, Light-Weight Structures, and Spacecraft Controls. These groups will determine the thermal protection system (TPS), material, internal structure, and mass of the vehicle. Currently, a Mars aerobrake with an AFE shape but 120 ft base diameter is being considered.

ACTIVITIES IN HYPERSONIC AERODYNAMICS

F. R. DeJarnette

Approximate numerical methods are being developed to calculate three dimensional inviscid/boundary layer and fully viscous shock layer methods. Both methods use Maslen's second-order pressure equation in a shock-oriented coordinate system. The inviscid/boundary layer technique is appropriate for higher Reynolds numbers whereas the fully viscous shock layer is applicable to the lower Reynolds numbers. The three

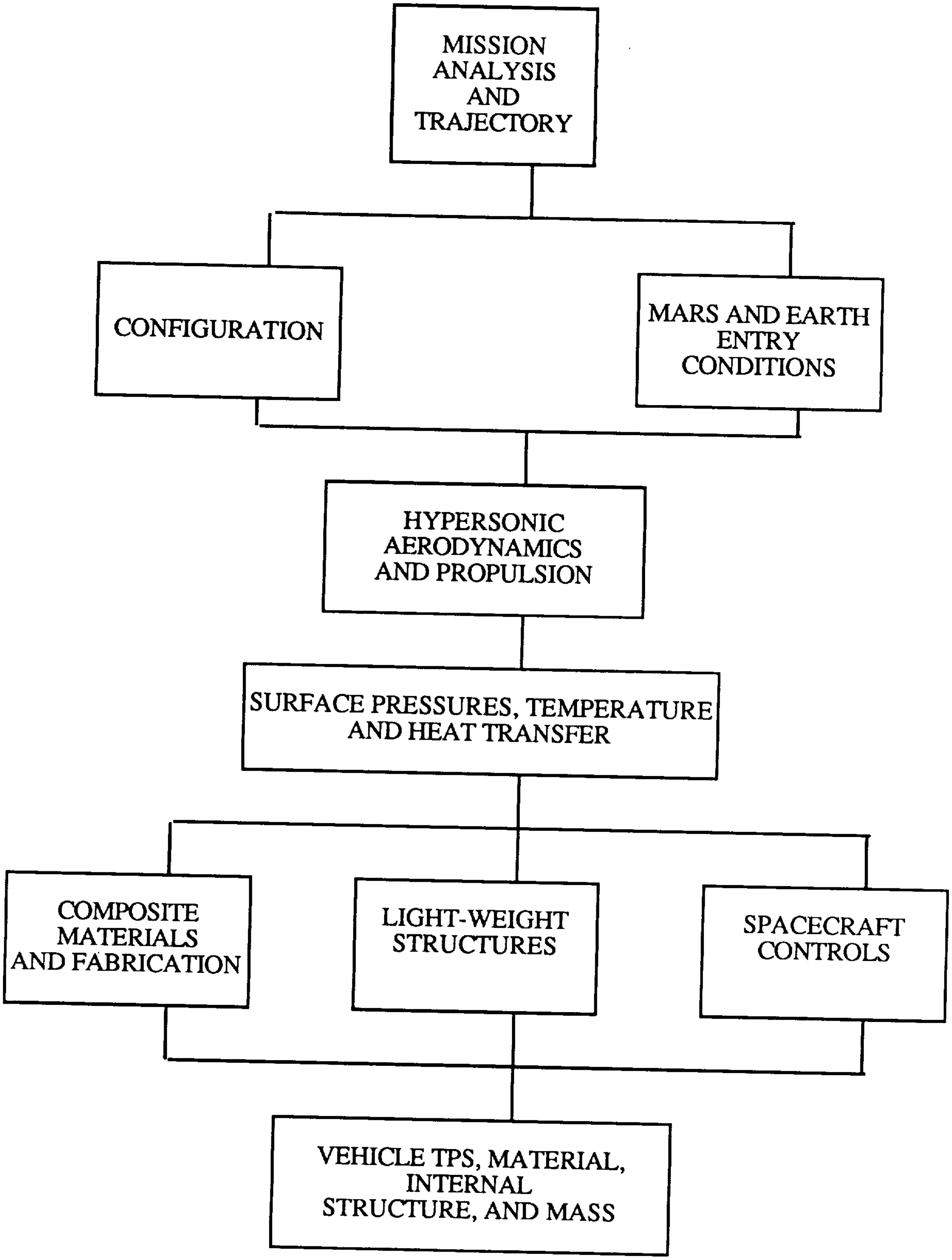


Figure 3. Methodology for Mars Spacecraft Design

dimensional inviscid method has been applied to blunted cones and an interacting boundary layer technique is under development. Axisymmetric fully viscous shock layer solutions have been obtained for a variety of blunt-nosed reentry bodies and this technique is being extended to three dimensional flow fields. A third effort involves development of an approximate nonequilibrium gas model to increase the computational efficiency of calculating nonequilibrium hypersonic flows. The research involving the approximate numerical methods is under the direction of Dr. F. R. DeJarnette with the assistance of four graduate students and in cooperation with Mr. Vince Zoby, Dr. Peter A. Gnoffo, and Dr. Kenneth Sutton of the Aerothermodynamics Branch at NASA Langley Research Center.

W. C. Griffith

Activities focus on two areas; establishing firm plans with NASA-Ames Laboratory for cooperative research in experimental aerothermodynamics, and developing student interest in the future of spaceflight.

Through discussions with Steve Deiwert, Gary Chapman and Anthony Strawa of Ames, Fred DeJarnette and Wayland Griffith have set plans for Griffith and three graduate students to be at Ames this coming summer. Mr. Jim Packard is an M.S. candidate working under Griffith's supervision, J. Evans Lyne, M.D., is a Ph.D. candidate also planning an experimental thesis. Dean Kontinos, a CFD student of Scott McRae, will spend the summer there.

Activities to develop student interest range from high school to graduate school. Under the Mentor Program of the N.C. School of Science & Math, Skip Everhart spent every Tuesday afternoon this year working on Earth-Mars transfer orbits and their associated flight times and arrival velocities. Two high quality slides for use by the M^2RC were prepared and much enthusiasm engendered. Skip has been admitted to NCSU and plans to major in Aerospace Engineering.

Two aerospace engineering students, David Wu and Kevin Kinzie, completed the study of multi-pass aerobreaking for Earth return of geosynchronous satellites that they had started as juniors under the College's Engineering Scholars Program. Kevin has extended this work to include the effect of lift for a paper at the Student AIAA Conference in Atlanta in April entitled, "The Use of Multipass Aerobraking for a GEO and LEO Transfer". A conclusion is that lift up while approaching perigee and lift down after leaving perigee may be desirable for ultimate capture by the Space Shuttle.

While necessarily pitched at the level of the student participants, these orbit transfer and aerobreaking studies are steps toward a systematic examination of some planetary mission system questions. Single pass vs. multi-pass aerobraking and using drag only vs. both lift and drag in reducing total propulsion requirements pose a set of questions having both high educational value to upperclass students and practical interest. Can multiple passes at relatively high altitudes reduce aerobrake thermal and structural loads significantly? What are the relative propulsion requirements for atmospheric roll control of lifting aeroshells vs. exo-atmospheric orbit adjust? To what subsequent uses could an aeroshield for deceleration into a Mars orbit be put? These and related questions will be studied during the coming year in connection with teaching MAE 453, Space Flight.

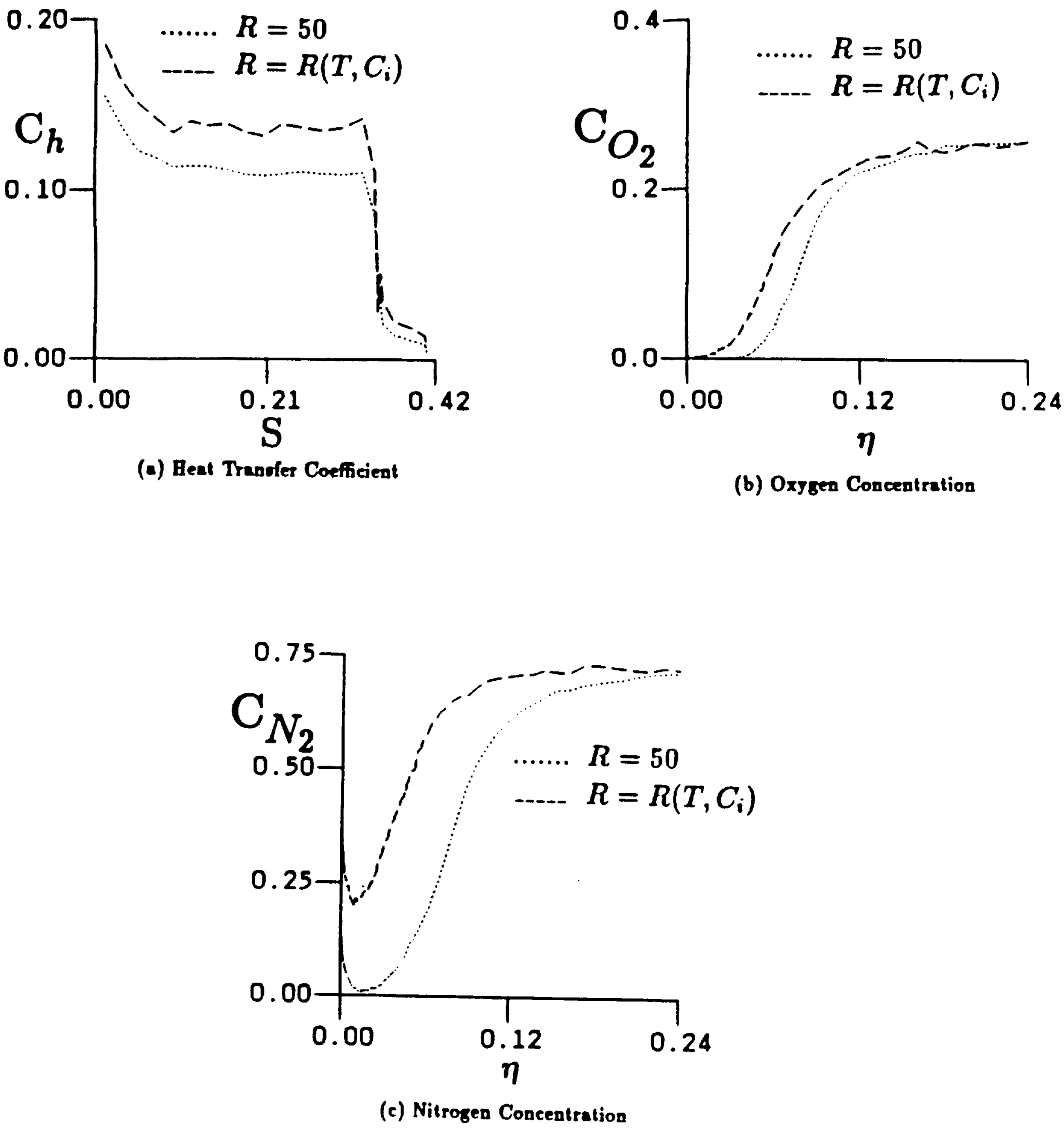
Supported as part of the NASA-ONR-USAF Hypersonic Aerodynamics Research Program the following experimental work guided by Griffith in cooperation with the Aerodynamics Branch, Naval Surface Warfare Center-White Oak is relevant to the M^{2}RC. The first year (1987) Griffith and one M.S. candidate started working at White Oak. J. Craig McArthur completed his M.S. in March (1989) on "Laser Holographic Interferometric Measurements of the Flow in a Scramjet Inlet at Mach 4". Two jointly authored papers have been given at AIAA meetings and a further paper has been submitted to AIAA for regular publication. Craig has accepted a job at NASA-Lewis Laboratory.

The second year (1988) two more students started at White Oak. David Witte submit tedhis M.S. thesis in May. His work compares heat transfer to a slender cone with a protuberance in Mach 14 flow as determined from embedded thermocouples and from an infrared scanning system. Susan Hudson is making a systematic study of nitrogen supercooling to non-equilibrium states below the triple point in hypersonic wind tunnels. A report on part of this work will be presented at the 17th International Symposium on Shock Waves & Shock Tubes in July and a joint paper has been accepted for publication in the Proceedings. The very large 25 K isobaric supercooling observed has major implications for future hypersonic tunnel design if our further research confirms present interpretations. For Mach 18-20 flow the required tunnel supply temperature may be reduced by about 1000°F. Susan will return to the White Oak Laboratory for a second summer and expects to complete her M.S. work next Fall.

The NSWC-White Oak has set plans to share in the cost of this Hypersonics Program. Starting this year they will pick up Dr. Griffith's summer costs and those of all second year graduate students working at the Laboratory. This arrangement permits us to increase the number of student participating. Once our credibility is established with the Ames Laboratory on the M^2RC Program, we hope to arrange a comparable sharing plan.

H. A. Hassan

The current activity using the Direct Simulation Monte Carlo (DSMC) method centers on a study of coupled vibration-dissociation[4] and a new method for simulating reentry plasmas[5,6]. The first study, which is motivated by the recent work of Sharma, Huo and Park, treats dissociation as a two-step process. Thus, only molecules in the higher vibrational states were allowed to dissociate. The model was used to study the flow past the project fire vehicle. Because of the wide range of temperatures encountered in the flow field, it was necessary to introduce a vibrational relaxation number, R, which is species and temperature dependent in place of the traditional constant number. Figure 4 shows the influence of the two-step dissociation model on the heat transfer coefficient C_h,



(a) Heat Transfer Coefficient

(b) Oxygen Concentration

(c) Nitrogen Concentration

Figure 4 Effects of Subspecies Concept (Project Fire, Complete Configuration) and the concentrations of O_2 and N_2 along the stagnation streamline. As is seen from the figure, the coupling of dissociation and vibration has a profound effect on the results.

The next study deals with Monte Carlo Simulation of reentry plasmas. The traditional implementation of the DSMC ties the electron to an ion at all times. Thus, the electron is not allowed to move freely. However, the electron temperature is based on the velocity of the electron. The present work uses the concept of ambipolar diffusion to calculate the electric field. Electrons and ions are then allowed to move freely consistent with the electric field present. Figure 5 compares the electron temperature using the traditional method and the alternate or present method. The oscillations ahead of the shock indicated in the figure are a result of the fact that fewer electrons exist in front of the shock.

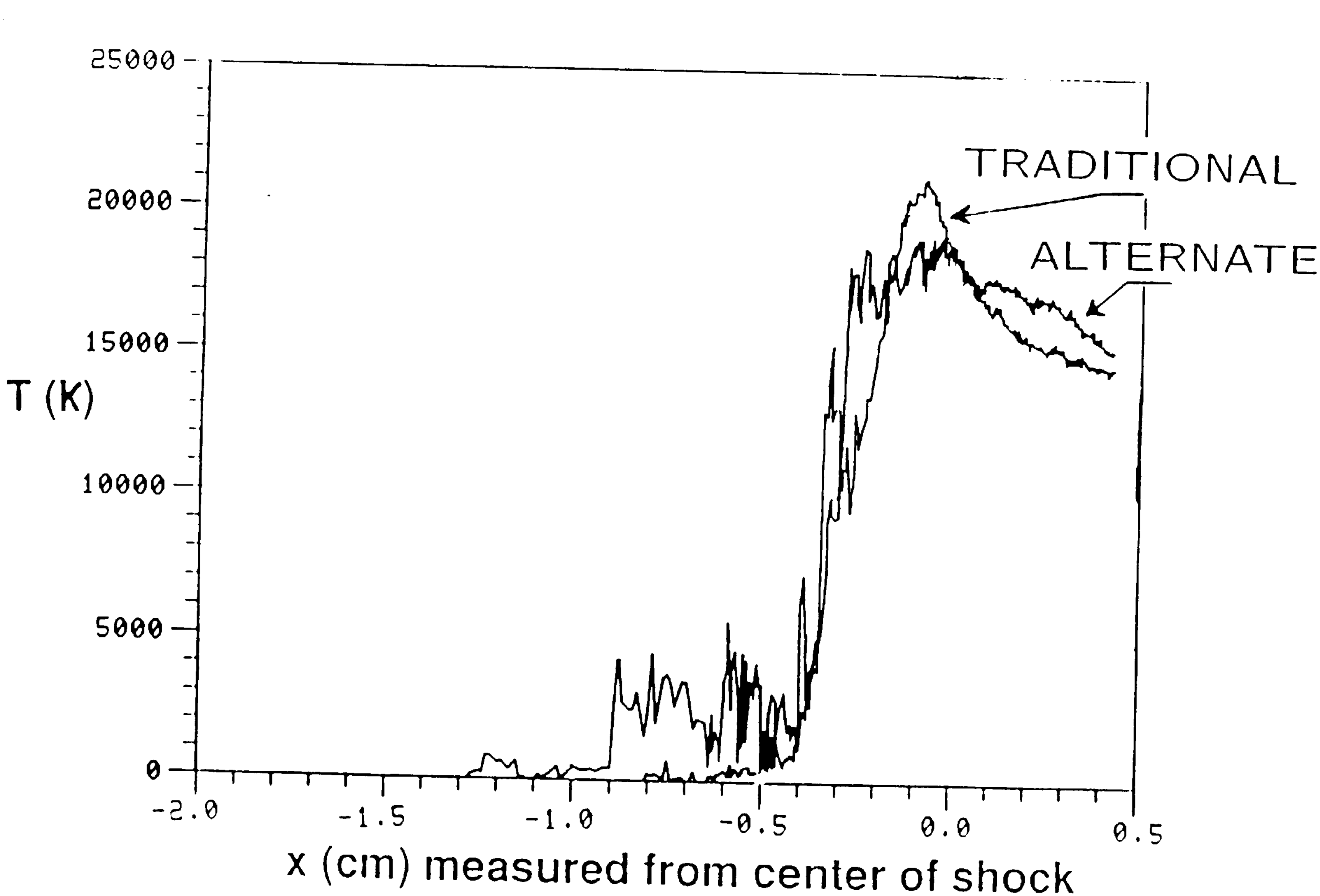
D. S. McRae

Work is proceeding in two directions, with one project being funded by the Hypersonic Aerodynamics Program and one being funded under the Mars Mission Center. This research is being carried out with the long term goal of providing accurate and appropriate techniques for computing flow over the full range of shapes being considered for the Mars Mission Aerobrake. The primary emphasis of this work will be accuracy with efficiency gained by taking advantage of present and future computer architectures.

The first project (funded by the Hypersonic Aerodynamics Program) is to install equilibrium and non-equilibrium chemistry model in the explicit upwind parabolized Navier-Stokes Solver recently developed by Korte[7-9]. The accurate results obtained by use of this code to compute the flow over a generic hypersonic vehicle Figure 6 are evident in Figure 7 where Mach number results are compared with a full Navier Stokes code using an implicit technique[10]. The excellent accuracy obtained with this code in comparison with experiment and full Navier Stokes results makes it a prime candidate for inclusion of chemistry effects. Note that it was originally intended to use a code by Gielda (on which Korte's is based) as an interim step for this work. However, we believe that the excellent

FIGURE 5

ELECTRON TEMPERATURE THROUGH SHOCK



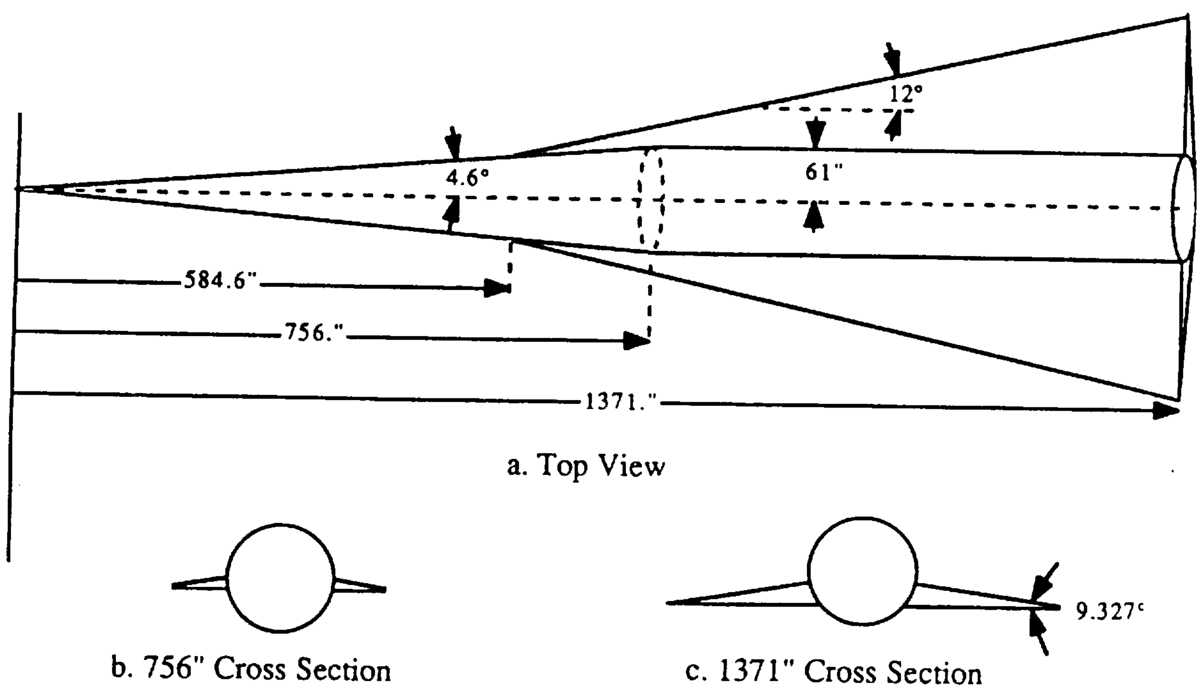


Figure 6 Generic airplane configuration.

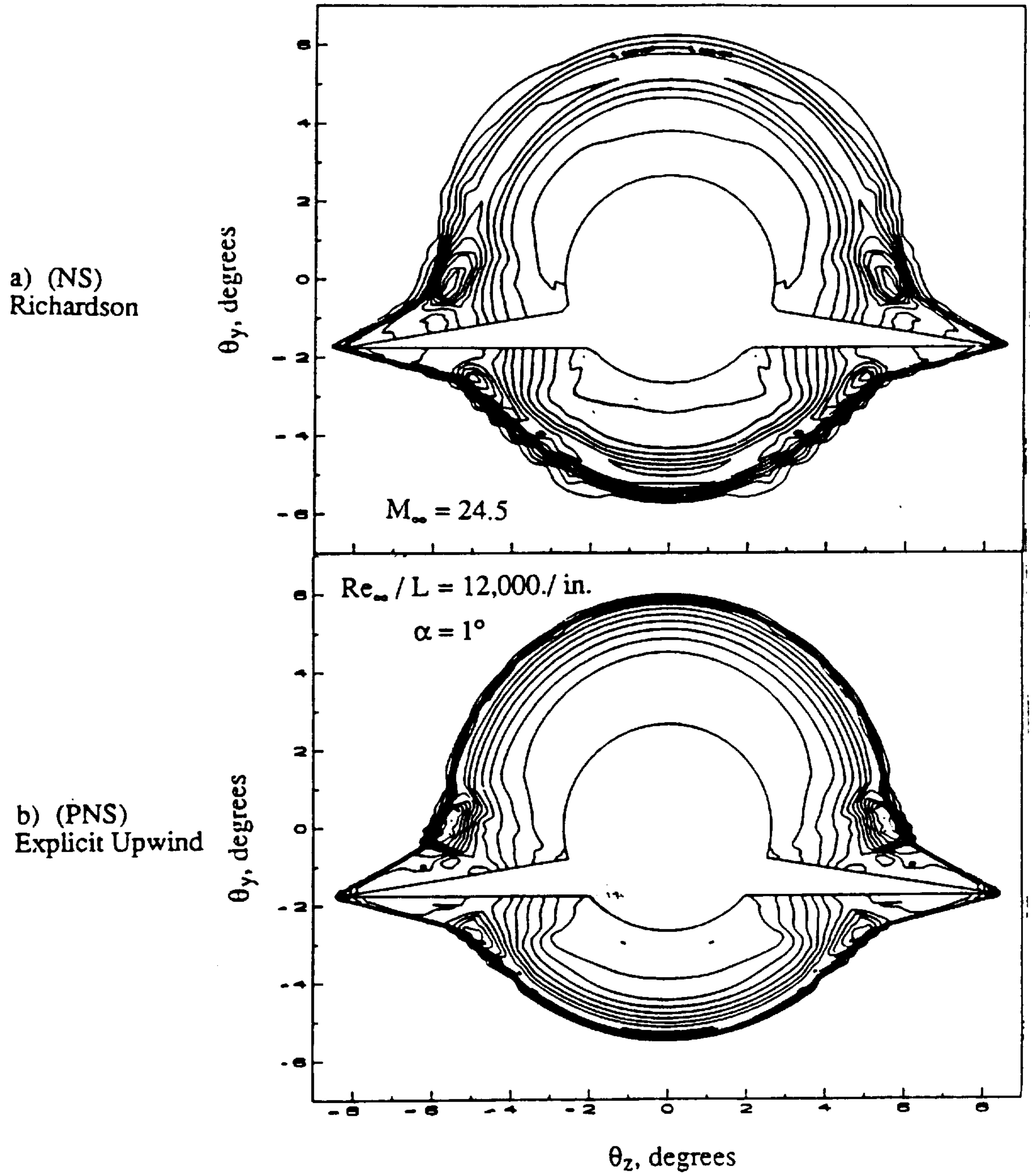


Figure 7 Comparison of computed pressure contours at station 1304 inches.

results obtained with Korte's code should be capitalized on. This work will be continued at NASA Langley Research Center in the summer of 89 in the Computational Methods Branch.

The second project (funded by M^2RC) will involve developing a code for solving the full Navier Stokes equations over general aerobraking configurations, including flow and heating interaction with structure and modules located behind the aeroshell. This code will be based on an extension by Korte of a rotated upwind scheme used for high angle-of-attack results[7-9]. A flux difference split Roe's solver involves the solution of an approximate Riemann problem in each coordinate direction. The combination of the separate Riemann problems does not always give accurate results when the assumed pressure discontinuities on which the Riemann problem is based cut diagonally across the Mesh stencil (Figure 8 from reference 8). The difficulty may also occur at symmetry boundaries. This problem will be alleviated by use of a local coordinate system rotated to coincide with the pressure discontinuity. This will allow the solution of a single Riemann problem with standard differences parallel to the shock wave. This work will be carried out in cooperation with the Applied Computational Fluid Dynamics Branch at NASA Ames Research Center beginning in the summer of 1989.

J. N. Perkins

This research is coordinated with the Experimental Aerodynamics Branch, Space Systems Division, NASA Langley Research Center.

1) Nozzle Design: The design of a total of eight axisymmetric, contoured wind tunnel nozzles ranging in Mach number from 6 to 20 was completed. The classical approach of iteration between a method of characteristics algorithm coupled with a state-of-the-art boundary layer code was used to design all nozzles. Limitations of this approach when applied to thick high speed boundary layers were investigated using a Navier Stokes analysis code. Working gases included ideal air, thermally perfect nitrogen, viral CF_4 and

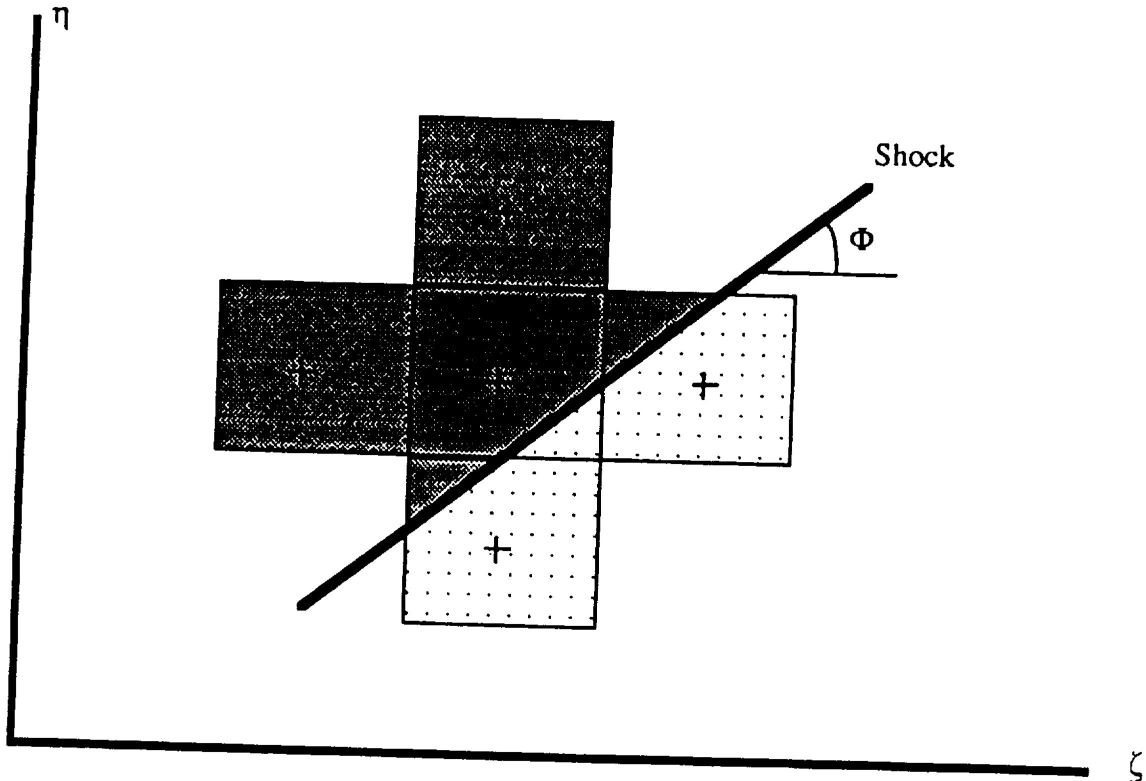


Figure 8 Shock angle in the computational plane.

helium. Agreement between the design conditions and Navier-Stokes solutions for ideal air at Mach 6 was good. However, all other designs at Mach numbers between 13.5 and 20 showed poor agreement. It is proposed that a study be initiated to develop a design approach using a parabolized Navier Stokes solver. (Jim Benton, the graduate student associated with this effort, completed the requirements for the Master of Science degree).

2) Generic Three-Dimensional Scramjet Inlet Investigation: A parabolic design of a 3-D scram jet inlet to be tested in the Mach 10 tunnel at NASA Langley Research Center was completed. A Navier Stokes solver was used for the design study. Parameters studied included sidewall sweep angle, contraction ratio, and cowl position. In addition, the location of instrumentation such as pressure sensors was optimized using the results of the Navier Stokes Solutions. At present, the model is being constructed, and tests are planned for the latter part of 1989.

In addition, to train Scott Holland, the graduate student associated with this effort, existing models of generic, sidewall compression inlets were tested in the NASA Langley Mach 6 CF_4 tunnel. The effects of cowl position, contraction ratio and Reynolds number were investigated. Pressure measurements on the sidewalls and cowl were made. In addition, schlieren movies were made for flow visualization.

3) Hypersonic Nozzle Afterbody Study: A parametric study of aircraft nozzle-afterbody configurations at hypersonic speeds is being carried out using a 3-dimensional Euler solver. Upon completion of this study, static tests of those shapes which appear to offer the greatest increase in performance will be carried out at NASA Langley by Marc Kniskern, the graduate associated with this effort.

SPACECRAFT CONTROLS

L. M. Silverberg

Vehicle design curves for aerocapture indicate aeroshell seizes on the order of 50 ft or more and aeroshell weights strongly driven to a minimum[11]. This implies that an efficient aeroshell will be quite flexible and may require active control to ensure that the aeroshell retains the correct shape for aerodynamic purposes. Initial work has centered on developing decentralized control algorithms for large flexible structures. A series of experiments is being developed to demonstrate how active control can be used to control the shape and to maneuver flexible structures using decentralized control algorithms.

The series of experiments include six experiments that build upon each other. The first experiment demonstrates how distributed displacement and velocity profiles can be synthesized from interpolated strain gage measurements. This experiment was completed in January 1989. The second experiment demonstrates how on-off jets can be used to uniformly damp the motion over the surface of a structure using decentralized control algorithms. This experiment was completed in May 1989[12,13]. The measurements of displacement and velocity needed for the control algorithm, are extracted from the synthesized strain gage measurements developed in the first experiment.

Analytical studies have been conducted in tandem. The globally optimal solution to the control problem was solved in order to obtain a theoretical optimum[14]. The decentralized control solutions were then compared to the theoretical optimum. The comparison reveals fuel consumptions for decentralized control extremely close to the theoretical optimum (within 99.5% for most cases).

A new cooperative agreement between the Spacecraft Controls Branch at NASA Langley Research Center and ourselves supports two more graduate students to further develop decentralized control methods for flexible maneuvering spacecraft. The students are John Meyer who will be completing his M.S. degree and beginning his Ph.D in

Aerospace Engineering, and Rick Gardiner who completed one year of study toward the M.S. degree in Aerospace Engineering.

COMPOSITE MATERIALS AND FABRICATION

This interdisciplinary work pertains to composite materials' processing and fabrication from the textile performs, mechanical property evaluation, and preliminary modeling. The primary emphasis has been in improving the composite processing and fabrication techniques leading to improved test specimens, and in generating meaningful and selective mechanical property data. The fabrication, testing, and analysis of the textile pre-form composite materials during this year is designed to gain experience with their behavior.

Composite Fabrication Laboratory

The laboratory location was selected in late October at A & T and the site preparation began almost immediately. The Composite Fabrication Laboratory contains an area of about 1500 square feet including a 100 square foot humidity controlled room where humidity sensitive prepregs and other materials can be prepared and loaded into curing fixtures. The major equipment items to fabricate organic composites have been moved into place and the installation is essentially complete. The major equipment items include a compression press (150 ton, 18" × 18" platens), an autoclave (13" × 13" × 36", 750°F, 330 psi), a low temperature plasma (12" Dia × 24", 1500 watt, 13.56 MHz RF), and a filament winding machine (maximum mandrel envelope – 14" diameter by 18" long). Various supporting equipment such as vacuum pumps, vacuum chamber, vacuum oven, ovens, Carver press, refrigerator and electronic scales are in service. A new explosion-proof hood is awaiting venting. The autoclave is new and has not yet been operated at A & T. Assistance to check-out the equipment will be obtained from the manufacturer after the nitrogen supply manifold has been installed. The filament winding machine is on loan from the Chemistry Department at Lawrence Livermore National Laboratory. At the time of installation, a note was found on the control panel to the effect that the longitudinal wrap controls were out of order. The equipment is approximately 15 years old so the repair of this circuit may be difficult. The winding machine was last used at the Oak Ridge Y-12 plant. This problem is being discussed with Mr. David Post at the Y-12 plant and Mr. Jay K. Lepper at Lawrence Livermore National Laboratories. A creel and an impregnation bath are also required before the filament winding machine can be operated. An attempt is being made to obtain a suitable creel.

Composite Fabrication

Dr. Aly El-Shiekh and Dr. Monsur Mohamed, NCSU College of Textiles, have supplied many samples of graphite braid and woven 3-D textile preforms to A & T for fabrication into composite bars. The fabricated bars have all been six inches long by various rectangular cross-sections. These molded composite bars have been used for various purposes. Some have been used for "show-and -tell" samples to explain various points of interest to associates and others. Some have been returned to N. C. State for conducting various studies. A small group of samples have been given to Dr. Juri Filatovs for mechanical property evaluation. His findings are reported elsewhere in this report.

Thus far, only one basic process and two matrix materials have been used to fabricate the samples. The textile preforms have been fabricated from both Celion and Magnamite 12K tow graphite fibers. All samples have been molded in a stainless steel mold. The mold has a cavity with an adjustable width (0 to 0.75 inches) by 0.50 inch height and 6.0 inches long. The release agent for the mold is Trewax. This is a carnauba based wax normally used as a floor wax. After the wax is applied to the mold, the braid is cut into a six inch length. The braid is placed in the mold and the mold width is closed to fit the braid width. The mold width is finally set by the width of the nearest plunger width plus a 0.011 inch feeler gage. The feeler gage establishes the flash thickness dimension.

The mold width is fixed by tightening two screws. The braid is put back into the mold to check the width fit. The open ends of the mold are closed with a small piece of pressure sensitive lead tape.

The epoxy resin used for all experiments is Shell Chemcial's Epon 828. Two catalysts have been used. The initial catalyst was diethylenetriamine. These ingredients are weighed and mixed in a weight ratio of 100 parts resin to 11 parts of the catalyst. Later, it was decided Texaco Chemical's Jeffamine T-403 would be a preferred catalyst. This catalyst is used extensively for wet filament winding. It provides a tough resin matrix with a 4 hour pot-life, a 200 cps viscosity and a room temperature cure (if needed). A considerable amount of data on its use and properties are available in the literature[15,16]. It is used in a weight ratio of 100 parts resin to 43 parts T-403. The batch size of mixture has been 50 to 70 grams depending on the dimensions of the textile preform. After the two ingredients are mixed, the container is placed in the vacuum chamber. As the pressure is lowered, foam rises in the container. At some point in the evacuation (about 2 torr), the foam collapses, and the resin continues to boil. After it has boiled for several minutes, the vacuum is released and the evacuated resin is removed from the chamber.

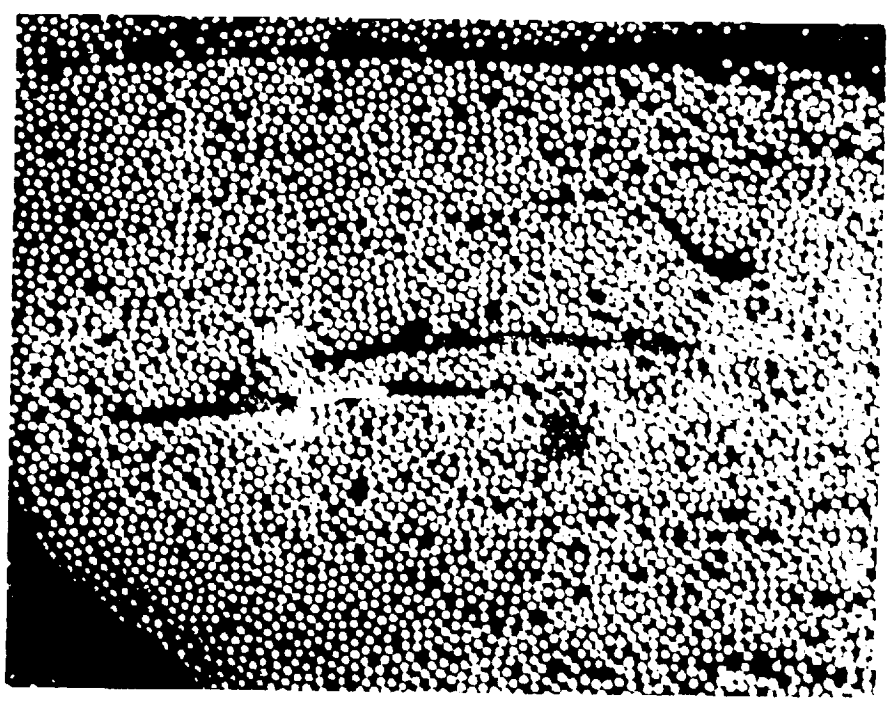
The cut ends of the textile preform are stabilized with a pressure sensitive tape wrap. Abut eight inches of textile preform is required for each molding as the end ties require about one additional inch per end. The textile preform is placed in the bottom of a clean container. The evacuated resin is poured over it until it is covered. The resin and textile preform are placed back in the vacuum chamber and the vacuum pump is started. The resin around the textile preform will bubble vigorously for a minute or so and then slow to a steady rate. The vacuum is again broken and the container of textile preform and resin is removed from the chamber. A thin layer of clear resin is added to the mold cavity to completely cover the bottom. The impregnated textile preform is carefully placed in the mold and pressed to the bottom of the cavity. The old containing the textile preform and resin go back into the vacuum chamber for a final evacuation. A vacuum of less than 1 torr is pulled and held for a few minutes and then released. A steel plunger is carefully pushed into the top of the mold cavity. The mold is moved to the Carver Press and the platens are gently closed. The excess resin flows out of the ends of the mold and out of the flash line beside the plunger. The press platen heaters are set to about 170°F and held for 6 or more hours. The mold is then cooled and the composite bar is removed.

Although this currently used process seems long, it may be eventually shortened. Any shortening of the process time however should be approached carefully. The initial evaluations of composites fabricated from this process indicate a nearly void-free product. To verify the quality of the composite processing, the moldings have ben studied both optically and with an SEM to determine the void content. The results have indicated that the present process does a good job of impregnating the textile braids in that no voids are present. The woven textile preforms have proven to be more difficult to fully impregnate. Only two samples have been molded and both have small internal voids. A more vigorous process will be evaluated when more woven textile preforms are made available for impregnation. Braid sample molding #5 is interesting in that it has a volume fraction of 57.5% Celion graphite fiber. This is the highest fiber content obtained up to this time. Optical photomicrographs of cross sectional ends are shown, Figure 9, to illustrate the tow and fiber arrangements within a molding. The photo taken at 50X illustrates the manor in which the 12K tows lays within the molding. The other three photos of various magnifications show how the fibers are arranged within the matrix.

Composite Work Plan

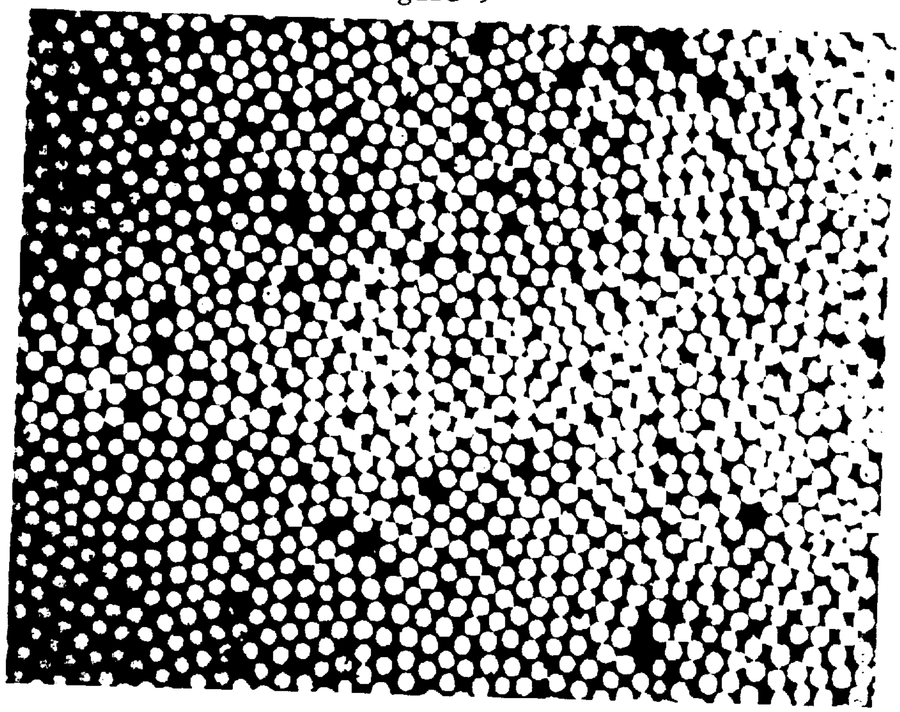
The initial composite work plan includes fabricating test coupons from various textile preforms, supplied by NCSU College of Textiles, and epoxy resin. Coupons fabricated from more conventional forms of fiber will also be made available for comparative studies. The evaluation of these samples will enable the investigators interested in mechanical properties and computer modeling to determine the viability of the

Figure 9 Braided Specimen #5, 50X Optical Microphotograph

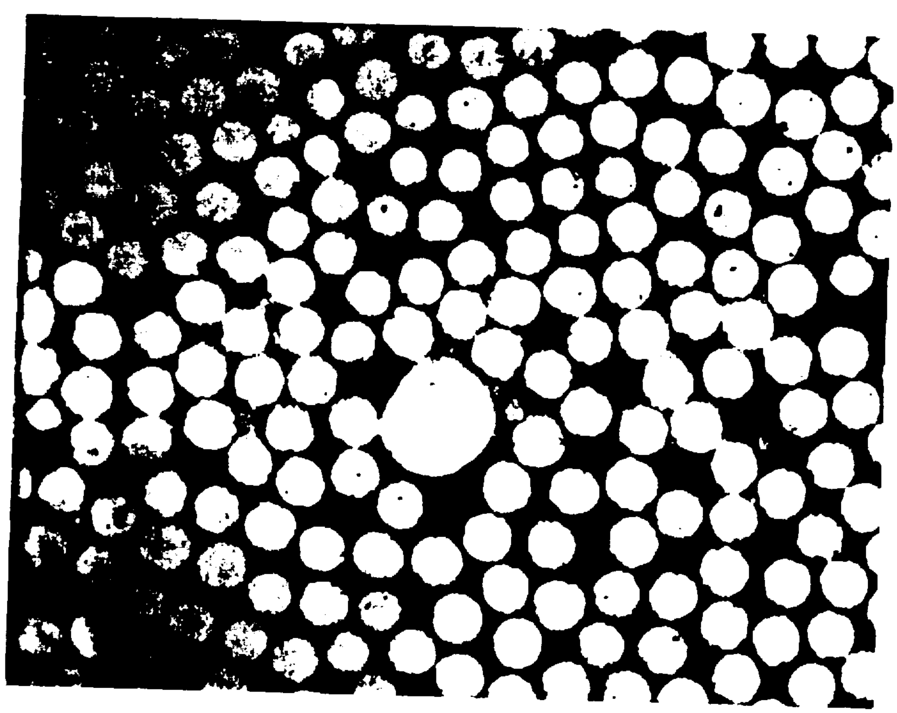


200X Magnification - Specimen in Fig. 9

Figure 9



400X Magnification - Specimen in Fig. 9.



1000X Magnification - Specimen in Fig. 9

various textile preforms as a structural material. It has been decided to "standardize" on the dimensions for composite test coupons fabricated from the various textile preforms. The tensile and flexural coupon will be $8.0 \times 0.75 \times 0.125$ inches. The compressive coupon will be $5.0 \times 0.50 \times 0.125$ inches. Three new molds have been ordered to provide the capability to mold these coupons at a reasonable rate. These molds will contain an improvement over the current mold in that positive stops will be provided to control the thickness dimension.

As noted earlier in the report, all of the composite bars have been fabricated by vacuum impregnation of the textile preform in a separate container from the mold. It is felt that this process can be simplified by vacuum transfer of the liquid resin directly into the mold that already contains the textile preform. A mold to experiment with this concept has been designed and is in the process of being fabricated.

The epoxy resin and catalyst being used at this time are only suitable for mechanical testing at room temperature. An epoxy resin with a T_g of 300°F will be used after the first round of mechanical properties are determined. Still later, polyimide resins with a T_g of 600°F will be used.

The polyimide resin may have to be fabricated into textile preforms as prepregs rather than dry fibers since polyimides are too viscous to impregnate by a vacuum process without the addition of a suitable solvent. The purchase of a laboratory size prepreger is being planned to enable A & T to supply polyimide/graphite prepreg to N. C. State that is suitable for forming into textile preforms.

Another phase of work involves composites fabricated from resin matrix materials in powder form. Techniques for introducing resin powders into tow and retaining it there will be investigated. The resins reserved for the process cannot be used in the normal liquid impregnation processes as they have neither a liquid stage nor solvent soluble. The use of fluid bed and electrostatic processes would be included in this study.

Micromechanics

This initial period was concentrated on developing approaches to braided materials: microscopy, fractography, and testing. The tests were learning tests; materials and methods were modified in response to suspected trends. Therefore, the early data is not fixed in that the level of care of preparation and testing play a large role. Once a trend emerged, the tests were repeated with increasing levels of care. This approach was necessitated by the limited number of specimens available and the lack of standardized tests for these materials. Due to their complexity and unique individual characteristics, each braid structure requires a specific approach and analytic model. This necessitates a broad investigation of deformation and failure mechanisms as they relate to structure, to identify principal variables and to acquire intuitive explanation.

Braid Geometry

To relate the structure to performance, the first necessity is a description of the structure. The fiber braiding parameters used by textilists are only partially descriptive of the final composite. What is required is a mapping of the external observables to the internal structure; this is not entirely unambiguous, and there is the added difficulty of an interdependence between the structure and fiber volume. The principal geometric features which have emerged as candidates for inclusion in a model descriptive cell for the structure are the cycle length of the fiber, inclination angles to axes, radius of curvature of fiber, fiber per-cent volume, and distribution and homogeneity of fibers in matrix. All of these must be extracted from the finished composite, mainly by measuring the surface projections of the inner structure. Figure 10 shows a typical braided composite. Figure 11 shows an isolated fiber tow. The actual geometry is not as sinuous, this being used for computational convenience.

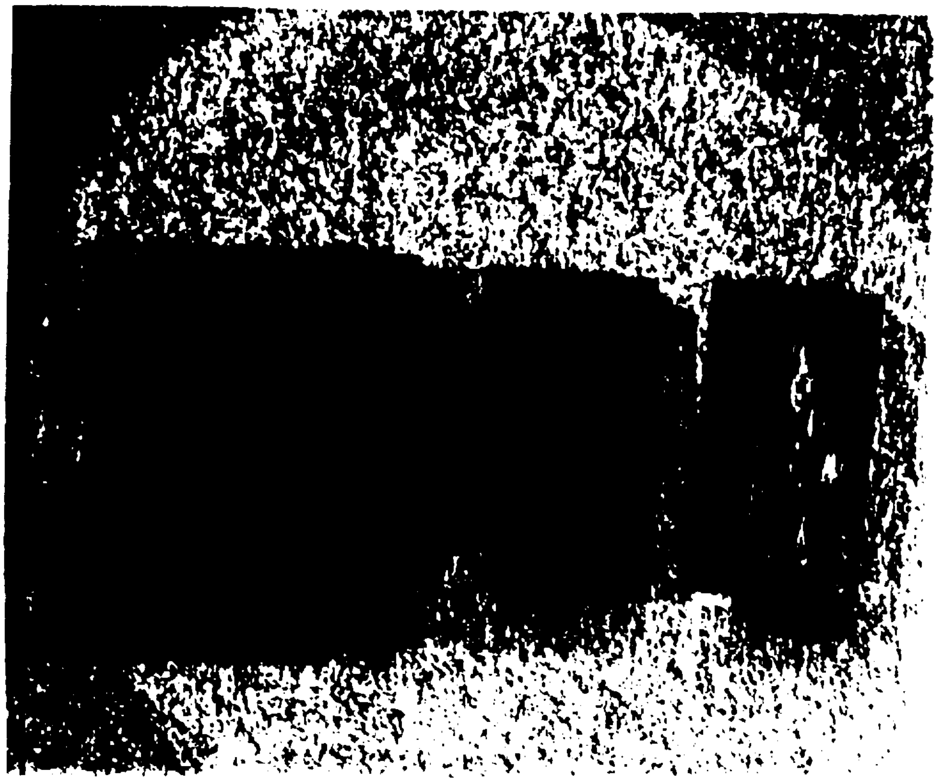


Figure 10 Typical Braided Composite Specimens

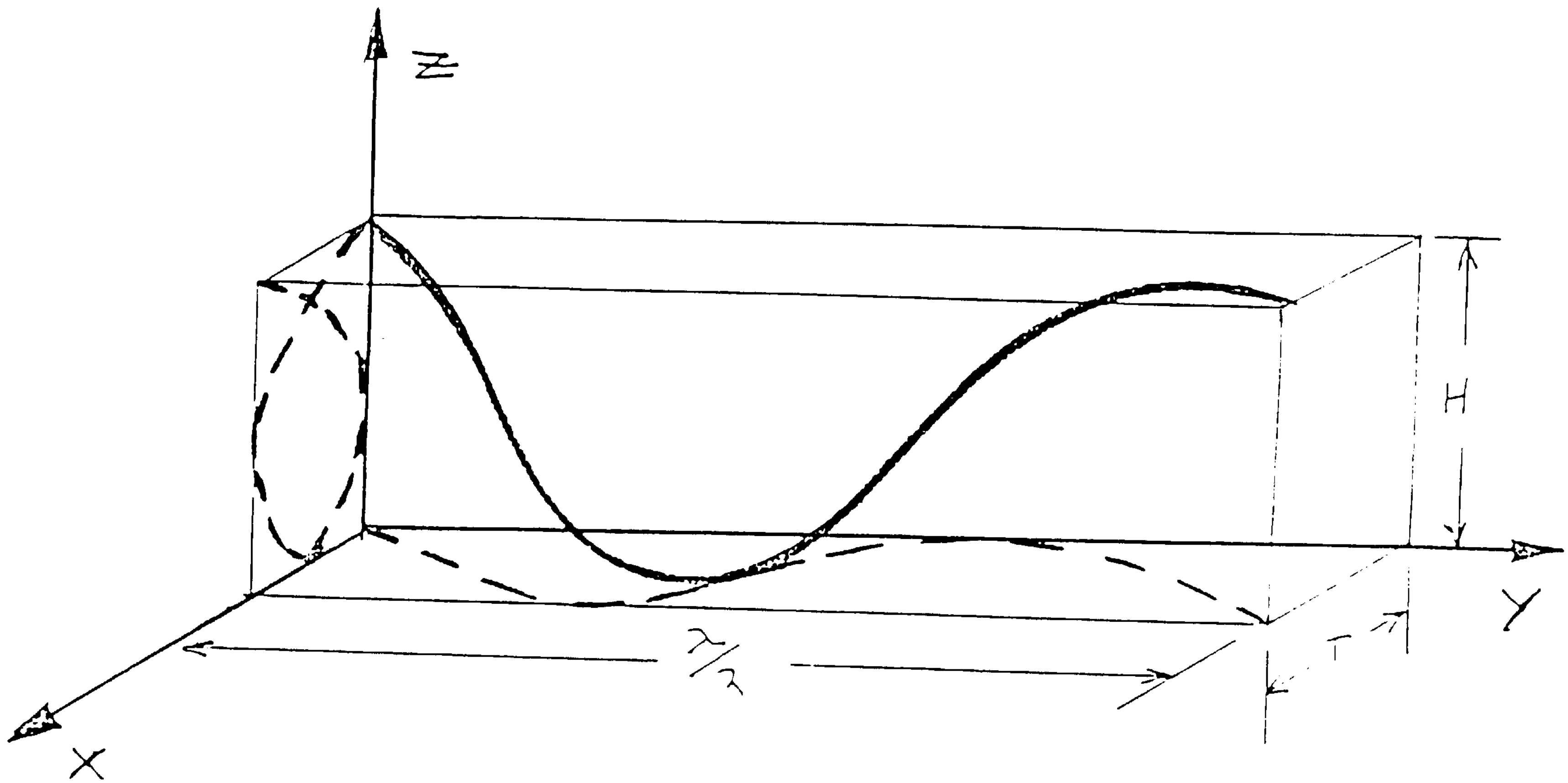


Figure 11 Isolated Fiber Tow

λ = Cycle Length

Y = Principal Braiding Axis (longitudinal Axis)

The final "unit/computational cell" may be a virtual structure incorporating statistical distributions for a description of the previously listed quantities, along with various averaging and interaction terms.

Testing

The following table contains some representative data from the first generation specimens. The axial compression tests were along the principal braid axis of Figure 10. The fixture was a moving piston type, with 1-inch diameter steel pistons, with all-ground surfaces. Loading was by a 10,000 lb. machine.

The principal testing variables were the parallelism of the loaded sample faces and the finish of the faces. If the faces were not polished with great care with 1-micron alumina, the fiber ends will be damaged and the failure would be a characteristic "mushrooming" of the ends. When the sample ends were not reinforced, properly prepared samples apparently are constrained by the polished ends and do not spread.

The matrix (unfilled sample) failed at the expected stress in shear along 45-degrees to the axis (Figure 12). The addition of fibers changes the failure mode to (usually) cleavage along the fiber tow interfaces (Figure 13). The tows generally act as units, with most failure occurring in the interface or matrix and on the closest interface to the 45-degree shear plane. There appears to be the expected correlation between the strength and per-cent fiber volume. The angle θ is the angle between the sample's longitudinal axis and the surface projection of the tows; it is roughly the angle of twist of the fibers. There appears to be an increase in strength with decreasing twist.

Other representative results are excerpted from the numerous data generated, and it should be again noted that these are learning and screening tests, and some backtracking to verify the trends is necessary. The ongoing work on structural geometry will also suggest other measurables. Compression strengths in any non-main axial direction were no higher than one-third of the values with axial direction. Bend tests were also disappointing, with

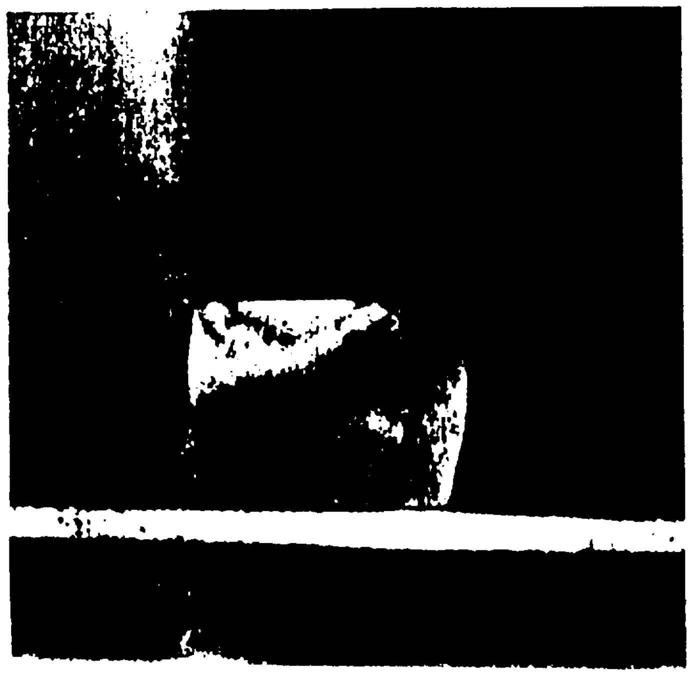


Figure 12 Matrix Failure (Compression)

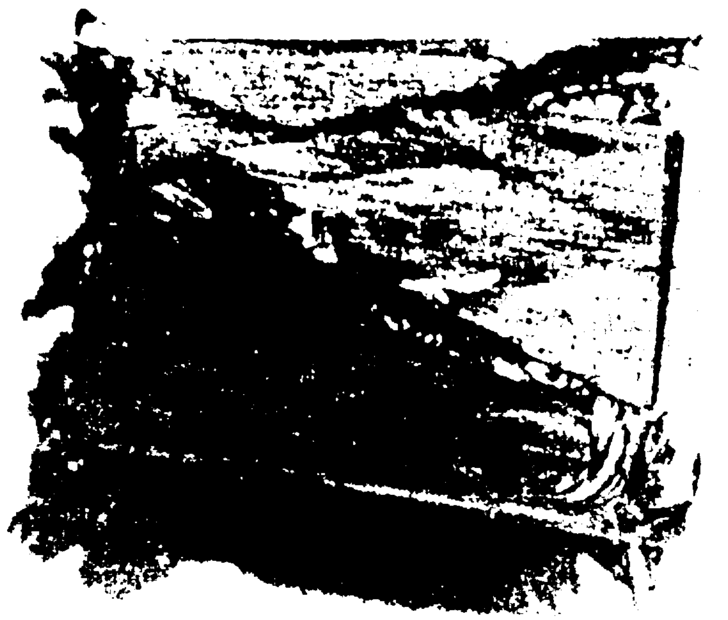


Figure 13 Compression Failure of a Braided Composite

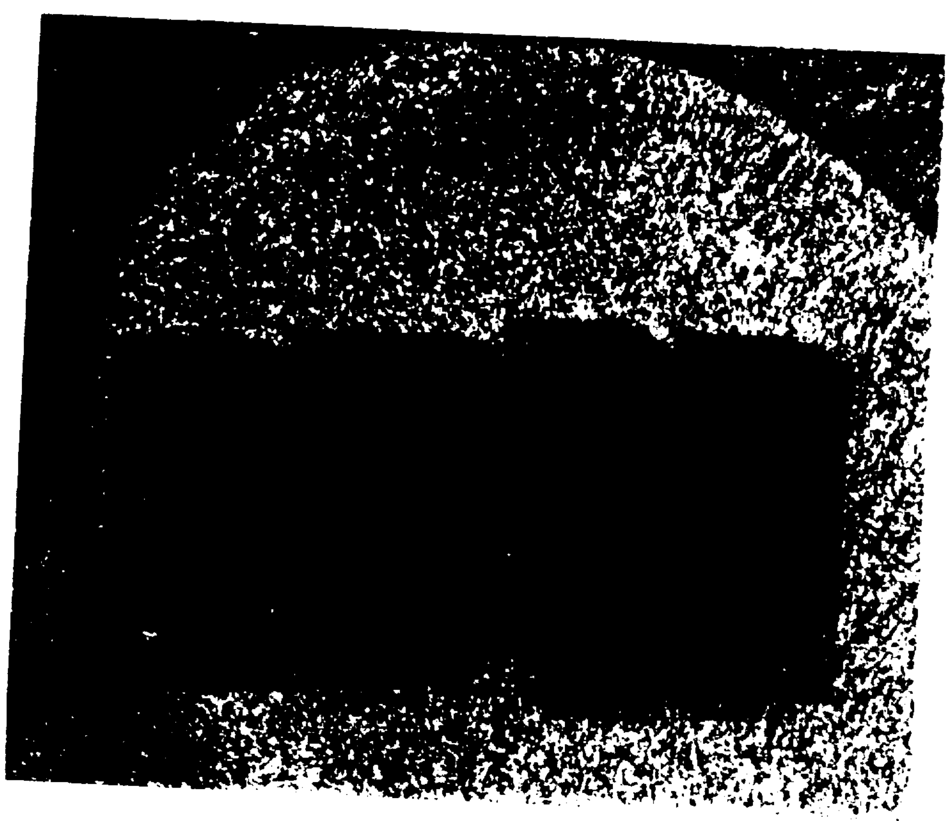


Figure 14 Mode I Crack-Extention Tests

failures by matrix yielding at the compressive side. Mode I crack-extension tests, as a prelude to energy measurement attempts, showed very brittle cleavage along the tow directions, regardless of the initial crack orientation (Figure 14).

Representative Test Results: Axial Compression Test

No.	Sample Type	Angle θ	% Fiber Volume	Failure Stress	Comments
0	Resin	–	–	13,400 psi	45° shear
1	Braid	12.5	48	77,000	Brittle Cleave
2	Braid	18	48	52,000	Brittle Cleave
3	Braid	10	37	65,300	Brittle Cleave
5	Braid	13	58	78,700	Very Brittle
18	Braid	3	47	109,000	Very Brittle

The samples have length of approximately 0.75 inches and a cross-section of approximately 0.38 by 0.15 inches.

Some Other Representative Tests

Bend Test: Samples from Tow 2 were tested in three-point loading with a support span of 1.35 in. The failure was a crush failure on the compression side, at a load of 190 lb.

Mode I Cracking: Saw cuts 0.025 in. wide and 0.250 in. deep were made parallel and perpendicular to the principal braid axis. On extension of the saw cuts, cracks followed the matrix-tow interface along the principal braid axis.

Compression Tests Perpendicular to the Principal Braid Axis: Specimens from Tow 4 and Tow 6 were tested in compression perpendicular to the direction in the previous list of compression tests. In all cases the failure stress of the samples was approximately one-third of the corresponding axial value.

The second generation of specimens is expected for testing, and these will have less lot-to-lot variability in both structure and fabrication. Thus, the testing procedures can be fine-tuned and a statistical data base begun. Complete stress-strain curves will be generated, and a more complete fractographic record made, including testing in-situ in the SEM. Concentrating on a single sample geometry will also allow cross-correlations among various tests, and earlier development of a representative geometric unit cell.

Modeling and Analysis

During this reporting period, Mr. Eric Goforth has met several times with researchers and graduate students in textiles at North Carolina State University to review and to make video tapes of the 2-step and 4-step braiding processes. He has completed taping of the 4-step braiding processes and he will return to film the 2-step process when it is again operational; it has been down for repairs.

The Textile College at NCSU has an algorithm of the fiber location and movement during the braiding sequences. It is coded in BASIC for an older Apple Computer. Prof. Craft has reviewed the procedure with Eric who is coding it for FORTRAN on A & T's UNIX system equipment. Eric will add a graphics component later and convert it to PC use. He is developing the code to allow a large number of geometries to be addressed. The location of each fiber in a section will be known at each braid cycle and the graphics display will review the shape of the fibers in simulated spacial view.

Mansour H. Mohamed

The manually operated model for weaving 3-D preforms has been modified and improved to produce high density and long samples. Slabs of dimensions 2" x $\frac{1}{4}$" x 20" have been produced from 6k, T300 carbon fibers with orthogonal structure and fiber volume fraction of 42-45%. Impregnation with epoxy resin has been tried by Dr. Fahmy and additional trials will be made by Larry Dickinson using the molds designed by Dr. Klang. Microscopical examination of the structure indicated that the fibers remain straight in all three directions, which is desirable to maximize their contribution to the strength and stiffness of the composite. Although infiltration of the tightly woven sample was not easily achieved, the micrographs showed good distribution of the matrix between the individual fibers. Samples of dimensions $\frac{3}{4}$" x $\frac{1}{4}$" x 12" have also been made and were impregnated by Professor Sadler at NC A&T. Micrographs of the structure were obtained using the scanning acoustic microscope showed some surface microvoids. Improvements in the impregnation technique are needed. Additional samples of $\frac{3}{4}$" x $\frac{3}{16}$" x 12" were made from Celion carbon fiber 12k in the warp and 6k in the filling. Impregnation of these samples is in progress.

In parallel with the hand weaving of structures, good progress has been made in the design, construction and assembly of an automated 3-D weaving machine. This machine uses mostly pneumatic drives to actuate all the motions. The shedding mechanism uses harness frames. This limits the structure to 3-D orthogonal. Plans are underway to buy an electronic jacquard head and to build another automated machine capable of weaving angle interlock and warp interlock structures in addition to the orthogonal one. Quotes have been obtained from the three manufacturers of electronic jacquard heads in the world. The features of each machine are being carefully studied. The price of the head (after considerable discount for the University) varies between $32,000 and $40,000. A new machine will have to be built and once the decision is made on the jacquard head selection, the design of the machine will start.

Testing of the composites made from the samples made already will be conducted on both campuses. Plans to make samples of 3-D woven preforms 6" wide, to impregnate them and test them for impact resistance properties have been discussed with Mr. Benson Dexter at NASA Langley. This work will be carried out this summer. The preforms for this work will be manufactured on the automated machine to insure uniformity and consistency of the structure.

So far two students have been funded by the Center. Mr. Larry Dickinson, a Master of Science student co-majoring in Textile Engineering and Science and Mechanical Engineering and Ms. Jinah Bennett, a Senior in Textile Engineering. Throughout the year, a visiting scholar from China Textile University, Shanghai, PRC, participated in the work, but received his funding from the College of Textiles. During the summer of 1989, another undergraduate in Textile Engineering, Ms. Nancy Marchele Evans, was hired. Recruitment of another graduate student is presently being actively pursued.

A paper has been accepted for presentation at the First SAMPLE International Conference in Chiba, Japan, November 28-December 1, 1989.

A trip to NASA Langley was made on October 20, 1988, I met with Mr. Benson Dexter and Mr. Gary Farley of the Applied Materials Branch. I plan to have work done in cooperation with them this summer in which the students will also participate.

A preliminary proposal to seek additional funding for the 3-D weaving work was prepared. This proposal was submitted to the U.S. Air Force Materials Laboratory at WPAFB in Dayton, Ohio and to the Army Research Office in the Triangle Park, NC.

Additional publications are listed as References 17 and 18.

Eric Klang

Information concerning the Mars Mission aeroshell was obtained by Dr. Klang at a recent Pathfinder meeting held at JSC. Several problem areas have been identified but perhaps the most significant one is the anticipated size of the aeroshell. Diameters of up to 120 feet are being studied, which of course means that some in space construction will be required (i.e., there are no launch vehicles capable of delivering the aeroshell in one piece). The most viable structural concepts involve using a segmented shell supported by a truss structure. The segments of the shell would be covered with an insulation material or ablator depending on the temperatures encountered. It is entirely possible that a mix of insulation and ablators could be used. The support truss would presumably be composed of composite tubes and aluminum joints. The function of the truss would be to transient loads between the aeroshell and the payload. The truss is not expected to encounter temperature changes greater than those seen by a typical orbiting space structure.

The current focus of the structures group of the M^2RC has centered on the possibilities of using 3-D composites for the aeroshell design. These materials may be used for stringers to stiffen the shell segments, joints for the truss and possibly the truss members themselves in connection with this work Dr. Klang and his student Genevieve Dellinger are working on developing a finite element model which can be used to predict the stiffness and strength of 3-D composites. The concept utilizes 3-D brick elements and numerical integration. The material properties within the element (at the Gauss Points) are chosen to match the stiffness of a unit cell of composite material. Ms. Dellinger will be working with Ray Foye at NASA Langley this summer and plans to have stiffness results by August. Strength predictions will follow with results anticipated by next spring.

More recently, Dr. Klang has begun to address some of the macroscopic or structural level issues. Initial work is directed towards the design of the shell segments. Questions such as, should the shell be a sandwich type or stringer stiffened skin type should be answered. Research at Langley has centered on the sandwich type of construction. Dr. Klang has begun work on the alternate stringer stiffened skin concept. Greg Washington will be working on this subject for his masters thesis. Focus areas for Mr. Washington will include the joint design for shell to shell and shell to truss attachment.

Sal Torquato

The transport and mechanical properties of composite materials depend, in a complex fashion, upon the microstructure of the materials, i.e., volume fraction, spatial distribution of the individual components, inclusion orientation, size distribution of the inclusions, interparticle contacts, etc. Our goal is to establish these property-structure relationships. One can then quantitatively relate changes in the microstructure to changes in the macroscopic variables. This has important practical implications, an example of which is the ability to construct composites with optimal properties.

Using this approach, we intend to study the following problems:

1. <u>Thermal Expansion Coefficient</u>

It is desired to compute the thermal expansion coefficient for a variety of nontrivial models of composites, both particulate and fiber-reinforced.

2. <u>Properties with Large Temperature Changes</u>

If the composite experiences large temperature changes, the individual material properties may change and thus the problem becomes a nonlinear one. Very little is known about nonlinear effects. We propose to examine this problem by beginning with the prediction of the effective thermal conductivity.

Aly El-Shiekh

Activities in the 3-D braiding laboratory are mainly in three areas.

1. Machine development:

(1) Partial reconstruction has been made on our first small scale automated 4-step 3-D braiding machine. The operation of the machine becomes easier, more versatile and reliable. Larger structures can also be braided on the upgraded machine.

(2) A small scale 2-step 3-D braiding machine to braid rectangular slabs was first developed and ran quite well. At the beginning of March, 1989, an expansion of the machine has been made, so that the machine can not only braid larger rectangular slabs but also braid structures such as T-beam, L-beam etc.

(3) A large 4-step 3-D braiding machine with 2,000 carriers has been constructed and running semi-automatically.

(4) A tubular 4-step 3-D braiding machine which could be used to braid net-shape rocket nozzles and other cylindrical shapes has been constructed and is currently under automation.

2. Process and structure analyses:

The 3-D braiding processes and the preform structures produced from them are being analyzed both theoretically and experimentally. Geometries of the preform structure are studied based on the real fiber interlacing. Structural parameters of the preform such as fiber volume fraction, fiber orientation and preform contour size as well as the relations among the parameters are investigated. This activity resulted in several publications as listed below:

3. Manufacturing and testing of preforms and composites:

Using the machines developed, many preforms have been produced from fibers such as Kevlar, Spectra, graphite, carbon/peek commingled, silicon carbide or mixture of them. The geometric shapes of the preforms include rectangular slab, I-beam, T-beam, L-beam, cylinder, solid rod, rocket nozzle etc. with different sizes. Some of the preforms have been made into composite materials with epoxy resin as matrices. As an initial effort, some low velocity impact and compression after impact tests have been conducted to evaluate the mechanical property of the 3-D braided composites panels. As a result, the two papers listed below are going to be presented to cover this topic.

Other activities besides these three areas which are partially associated with the M^2RC are the study of the composite material microstructure using scanning acoustic microscopy (SAM) and the analyses of the filament winding process. These activities resulted in the following publications:

The graduate student working on this project is Ms. Rona Reid who is mainly working on the effect of consolidation conditions on the properties of composite materials.

Currently she is developing a knowledge of the different techniques of consolidation. She will be also working very closely with Prof. Sadler and Dr. Oraby to develop know-how to surface treat fibers using plasma and other means. She will incorporate the surface treatment effect in her studies.

The undergraduate student working on the M^{2}RC is Ms. Cirrelia Thaxton who has been trained on the use of 3-D braiding equipment mainly the 4-step braiding. She has been helping in the preparation of samples designed by the researchers at A & T University for their study.

Other pertinent publications are listed in References 19-27.

A. A. Fahmy

Three graduate students are engaged in research in the area of composite materials. Harvey A. West, who has just successfully defended his Ph.D. dissertation, worked on the wear behavior of fiber reinforced composites relating it to both the orientation of the fibers relative to the wear plane and to the direction of sliding in this plane. After receiving his Ph.D. degree, he intends to stay in the department, which is fortunate for us since he is very familiar with the materials, techniques, and equipment we use. Jong Bong Kang is another Ph.D. student and is working on tensile properties, modulus, strength, and failure modes, of laminated composites along the thickness direction. We have examined these properties in the past in compression, both experimentally and analytically, but tensile properties are far more difficult to deal with experimentally. He is using samples of the double-ligament geometry and we are hoping to check this method against regular geometry samples hundreds of plies thick. Mr. Stefan Voss is concentrating on the thermal expansion properties of three-dimensional composites with both braided and woven preform reinforcements. However, our input this year to the Mars Mission program has been rather limited due to our late entry into the program. But, since we already had an ongoing research effort in this area, we managed to provide assistance and service to other members of the program. We helped in the preparation, from prepreg, of laminated panels using our heated platen press before one was acquired elsewhere, performed four-point flexure tests on braided preform composite samples, provided various samples, that have been well characterized by other techniques, for examination with the scanning acoustic microscope to ascertain its capabilities and possible use in the study of such flaws as delamination and fiber-matrix separation in three-dimensional composites. In addition, we experimented with the resin infiltration and curing of three-dimensionally woven preforms and the microscopic examination of the resulting composites. This work revealed that infiltration was a success in that complete wetting of the fibers by the resin was achieved.

A dilatometer recently acquired in my laboratory is now being put into operation. This is a sophisticated system with a temperature range of −150°C to 1600°C which can be programmed to follow predetermined heating and cooling cycles in air or a protective atmosphere. We are now in the stage of calibrating the instrument and gaining familiarity with the intricacies of programming. We have also made extensive inquiries from laboratories and makers of scientific instruments on the availability of thermal conductivity measuring systems and identified one which combines precision with versatility. An order is now being processed to purchase this unit. Modelling of composites with braided and woven preforms is also underway using finite element analysis and the computer code ELAS 75 which proved in our earlier studies to be efficient in dealing with anisotropic materials.

REFERENCES

1. "Exploration Studies Technical Report FY 1988 Status, Volume I - Technical Summary", NASA Technical Memorandum 4075, Office of Exploration, December 1988.
2. Walberg, G. D.; "A Review of Aerobreaking for Mars Missions", 39th Congress of the Internatinal Astonautical Federation, Paper No. IAF-88-196, Bangolore, India, October 8-15, 1988.
3. Tauber, M. and Bowles, J.; "The Use of Atmospheric Braking During Mars Missions", AIAA 24th Thermophysics Conference, Paper 89-1730, Buffalo, NY, June 12-14, 1989.
4. Olynick, D. P., Moss, J. N. and Hassan, H. A., "Influence of Afterbodies on AOTV Flows", AIAA Paper 89-0311, January 1989.
5. Carlson, A. B., Hassan, H. A. and Moss, J. N., "Monte Carlo Simulation of Reentry Plasmas", AIAA Paper 89-0683, January 1989.
6. Sharma, S. P., Huo, W. M. and Park, C., "The Rate Parameters for Coupled Vibration-Dissociation in a Generalized SSH Approximation", AIAA Paper 88-2714, June 1988.
7. Korte, John J. and McRae, D. S., "Explicit Upwind Algorithm for the Parabolized Navier Stokes Equations", AIAA Paper 88-0716.
8. Korte, John J., "An Explicit Upwind Algorithm for Solving the Parabolized Navier Stokes Equations", Ph.D. dissertation, N. C. State University, May, 1989.
9. Korte, John J. and McRae, D. S., "Numerical Simulation of Flow Over a Hypersonic Aircraft Using an Explicit Upwind PNS Solver", AIAA Paper 89-1829.
10. Richardson, P. F. and Morrison, J. H., "Displacement Surface Calculations for a Hypersonic Aircraft", AIAA Paper 87-1190.
11. Senior Design Project, "Design Curves for Aerocapture", North Carolina State University, May 1989.

12. Silverberg, L. and Redmond, J., "Uniform Damping Control Discretization", presented at the VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, May 8-10, 1989.

13. Silverberg, L. and Meyer, J., "Uniform Damping of Spacecraft Using On-Off Devices", presented at the VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, May 8-10, 1989.

14. Silverberg, L. and Park, S., "Globally Optimal Maneuver of Distributed Systems", presented at the 30th Structures, Structural Dynamics and Materials Conference, April 3-6, 1989; also submitted to *J. of Optimal Control Methods and Applications*.

15. T. T. Chiao and R. L. Moore, S.A.M.E. Quarterly, Vol. 3, No. 3.

16. Mohamed, Mansour H., Fiber-Tex 88 Conference in Greenville, S.C., September 13-15, 1988.

17. Mohamed, Mansour H., presented at the ASME Winter Annual Meeting held in Chicago, Ill., November 27-December 2, 1988. *Advanced Composites and Processing Technology*, MD, Vol. 5, ASME Book No., G00484.

18. Texaco Chemical Company, product bulletin, Jeffamine – Polyoxypropylene Curing Agents for Epoxy Resins.

19. El-Shiekh, Aly, "The Effect of Processes and Processing Parameters on 3-D Braided Preforms For Composites", SAMPE Quarterly, Vol. 19, No. 4, July 1988.

20. El-Shiekh, Aly, "Structural Mechanics of 3-D Braided Preforms for Composites, Part 2 Geometry of Fabric Produced by 2-Step Process", Fiber and Tex '88 Conference, Greenville, South Carolina, Sept. 13-15, 1988.

21. El-Shiekh, Aly, "Structural Mechanics of 3-D Braided Preforms for Composites, Part 3 The 2-Step Circular Braiding", ASME 109th Winter Annual Meeting, Chicago, Nov. 27-Dec. 2, 1988.

22. El-Shiekh, Aly, "On the Mechanics of 3-D Braided Preforms for Composites", The Gordon Conference, July 1989, New London, N. H.

23. El-Shiekh, Aly, "Effect of Braiding Process on the Damage Tolerance of 3-D Braided Graphite/Epoxy Composites", 34th International SAMPE Symposium, Reno, Nevada, May 8-11, 1989.

24. El-Shiekh, Aly, "The Effect of Unit Cell Size on Impact Damage Tolerance of 3-D Braided Graphite/Epoxy Composites", International Conference on Composite Materials-VII, Beijing, China, Aug. 1-4, 1989.

25. El-Shiekh, Aly, "On the Mechanics of Filament Winding, Part 1 A Generalized Model", to be presented at the 34th International SAMPE Symposium, Reno, Nevada, May 8-11, 1989.

26. El-Shiekh, Aly, "Characterization of Composites by Acoustic Microscopy", to be presented at the annual meeting of the Electron Microscopy Society of America, San Antonio, Texas, August 6-11, 1989.

27. El-Shiekh, Aly, "A Study on Composites Damage Using Acoustic Microscopy", to be presented at EMAG-MICRO'89-The Future of Microscopy, Sept. 13-15, 1989, The Royal Microscopy Society, Oxford, England.

INTERACTION WITH NASA CENTERS, INDUSTRIES AND OTHER UNIVERSITIES

Discussions have been held with personnel at the following organizations:

NASA Ames Research Center

Aerothermodynamics Branch
Drs. Gary Chapman, Steve Diewert, and Toni Strawa

Applied Computational Fluid Dynamics Branch
Mr. Mike Green

NASA Langley Research Center

Aerothermodynamics Branch
Drs. Peter Gnoffo and Kenneth Sutton

Applied Materials Branch
Drs. Benson Dexter, Gary Farley, and Howard Maahs

Fatigue and Fracture Branch
Drs. John Crews, Howard Maahs, and John Whitcomb

Polymeric Materials Branch - Dr. Terry St. Clair

Guidance and Control Division Chief - Dr. Willard Anderson

Spacecraft Controls Branch
Drs. Claude Keckler, Doug Price, and Bill Suit

Structural Mechanics Branch - Dr. James Starnes

Lawrence Livermore National Laboratory - Mr. Jay Lepper

Oak Ridge National Laboratory - Mr. David Post

McDonnel Douglas, Huntington Beach, CA
Mr. John Garvey and Dr. Robert Wood

Pratt & Whitney, West Palm Beach, FL - Mr. Wayne Pecic

Institute for Space and Terrestrial Studies and University of Toronto Space Institute
Drs. Phillip Lapp, Ian Howard and Rod Tennyson. Also Mr. Doug Ditto, Canadian Deputy Consul General

Corning Glass Works - Dr. Roger A. Allaire

RESEARCH WITH McDONNELL DOUGLAS SPACE SYSTEMS COMPANY

The Space Station Division of the McDonnell Douglas Space Systems Company is funding M^2RC to perform research on the design of an aerobrake for manned Mars transfer vehicles. Mr. Jon Hamilton, graduate research assistant, worked with the Space Station Division at Huntington Beach, California for the summer 1989 and will continue the research during the 1989-90 academic year. The research is being coordinated with Mr. John Garvey, McDonnell Douglas Space Systems Company, Huntington Beach, California.

RENOVATED AND NEW FACILITIES

An essential part of the program at A&T requires renovation of several existing facilities. The most urgent need is the development of a Composite Processing and Fabrication Facility. Renovation of this facilities is in progress and has an estimated completion date of October 31, 1989. Other existing facilities which required renovation are the Composite Materials Testing Laboratory, Light and Scanning Electron Microscope Laboratory plus several facilities for smaller scientific equipment.

Architects have designed an NCSU Research and Technology Development Building for the new Centennial Campus and the M^2RC will occupy about one-third of it. The plans call for offices for faculty and students, rooms for computers and work stations, a composite materials laboratory with a high bay area, an instrument room, and a processing room. The net square footage allocated for M^2RC is 6,700 and the scheduled completion date is January 1991. At that time, all of the activities of the M^2RC at NCSU would be moved to this new facility which is about one mile south of the main campus. The entire College of Textiles will also move into new facilities adjacent to the Research and Technology Development Building in 1990. Transportation will be provided for students and faculty between the main campus and the new facility.

SEMINARS AND COORDINATION OF ACTIVITIES

Faculty and students at NCSU and A&T coordinate their research by visits to the two campuses and televideo meetings held twice a month. Dr. S. Chandra of A&T worked in the Mechanical and Aerospace Engineering Department at NCSU from January 1, 1989 to June 30, 1989. He is presently working at NASA Langley Research Center on a one year sabbatical from A&T. Additional interchange of students and faculty between the two campuses are planned for the next year.

The faculty and students at A & T receive the televised seminar series, in composite materials, initiated from the University of Illinois. The following is a schedule of seminars for the Spring Semester, 1989. Students and faculty have an opportunity to interact with the speakers through telephone. These seminars are being televised live by GTE Gstar 1 Satellite (Ku-Band) from 4:00–5:30 p.m. (eastern time).

Date	Guest Speaker	Title of Presentation
2/10	Dr. Hatsuo Ishida Macromolecular Science Case Western Reserve Univ.	Interface Molecular Characterization of High Performance Composite Materials
2/24	Professor C. T. Sun Aeronautics & Astronautics Purdue	Intelligent Tailoring of Laminates
3/10	Dr. John L. Kardos Dir. Materials Res. Lab. Washington University	New Processing Science for High Performance Polymer-Matrix Composites
3/31	Dr. Paul Lagace Aeronautics & Astronautics M. I. T.	The Sensitivity of Kevlar-Epoxy and Graphic-Epoxy Structure to Damage from Fragment Impact
4/21	Professor R. A. Schapery Civil Engineering Texas A & M University	Mechanical Characterization Analysis of Inelastic Composite Laminates with Damage
5/05	Dr. N. J. Pagano Air Force Materials Lab Wright-Patterson, AFB	Issues in Micromechanical Modelling of Brittle-Matrix Composites
5/19	Prof. Zvi Hashin Mechanical Engineering Dept. Tel Aviv University and Professor of Mechanical Engineering University of Pennsylvania	Analysis of Cracked Composite Laminates

RECRUITMENT OF STUDENTS, FACULTY, AND STAFF

Both undergraduate and graduate students work with M^2RC. Undergraduate students typically work half-time during the summer and quarter-time during the academic year. Students with at least a B-average are recruited, and they are highly encouraged to continue into a graduate program. Currently there are 6 undergraduate students at NCSU and 6 at A&T.

A flyer was distributed nationally to recruit graduate students for both NCSU and A&T. It helped us recruit outstanding graduate students for the program. There are currently 12 graduate students supported by M^2RC and numerous other students in the program but supported by other sources. All students supported by M^2RC must be U. S. Citizens.

The following faculty were recruited during the year to work with the M^2RC:

1. Dr. Gordon K. F. Lee, spacecraft controls, NCSU.
2. Dr. Wadida Oraby, composite materials, A&T.
3. Dr. I. S. Raju, composite materials and modelling, A&T.
4. Dr. F. Yuan, light-weight structures and materials, NCSU.

A faculty member with expertise in mission analysis and vehicle design is being recruited.

Staff recruited for the Center are:

1. Bruce Alston, Mechanical technician, A&T.
2. Robert Jackson, polymer processing and fabrication technician, A&T.
3. Bill Roberts, machine shop technician, NCSU.
4. Emily Tate, administrative assistant, NCSU.

MARS MISSION RESEARCH CENTER FUNDING

Cost Sharing by Universities

		YEAR 1 (June 1, 1988 to Feb. 28, 1989)	YEAR 2 (March 1, 1989 to Feb. 28, 1990)
Faculty		$ 0	$ 276,622
Support Personnel		0	13,447
Equipment		64,000	64,000
Space:	New (7,000 sq. ft.)		465,503
	Renovations	154,673	125,000
TOTAL COST SHARING		$218,673	$ 944,572
NASA Funding:		500,000	1,962,518
TOTAL (NASA & UNIVERSITIES)		$718,673	$2,907,090
Cost Sharing (% of NASA Funding):		44%	48%

CONCLUDING REMARKS

The Mars Mission Research Center has started developing the computational facilities, laboratories, and equipment necessary to pursue cross-disciplined research in the areas of (1) hypersonic aerodynamics and propulsion, (2) light-weight structures and controls, and (3) composite materials and fabrication. Students and faculty are involved in developing the technology which is needed for the design of an aeroshell for space transportation systems. In addition, students are being trained in space related topics which will give them the background necessary to pursue careers in the space program at universities, industries, or governmental laboratories. Interactions with other organizations and NASA Centers are being pursued to enhance the academic and research programs at both North Carolina State University and A&T State University.